REPORT RESUMES

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THE ELEMENTARY SCHOOL TRAINING PROGRAM IN SCIENTIFIC INQUIRY.
BY- SUCHMAN, J. RICHARD
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THE PURPOSE OF THIS STUDY WAS TO INVESTIGATE SPECIFIC METHODS OF DEVELOPING THE INQUIRY SKILLS OF ELEMENTARY SCHOOL CHILDREN. ACTIVITIES INVOLVED SELECTING SPECIFIC METHODS, GATHERING MATERIALS, AND TRAINING QUALIFIED TEACHERS. A 24-WEEK, INQUIRY TRAINING PROGRAM WAS GIVEN TO FIFTH- AND SIXTH-GRADE CHILDREN WHICH INCORPORATED--(1) ANALYSIS, (2) COMPARISON, (3) ISOLATION, AND (4) REPETITION AS APPLIED TO PROBLEM EPISODES IN PHYSICS. NEW FIRM CONCLUSIONS COULD BE DRAWN FOR A DEFINITE LEARNING THEORY OR FOR THE PRACTICAL EFFECTS OF ANY SUCH THEORY OVER A LONG-RANGE PERIOD OF TIME. THERE WERE, HOWEVER, MARKED EFFECTS ON THE MOTIVATION, AUTONOMY, AND QUESTIONING FLUENCY OF THE EXPERIMENTAL GROUP OF CHILDREN. THE SUGGESTIONS FOR FUTURE RESEARCH IN THIS AREA PROPOSED THE INCORPORATION OF--(1) CONCRETE PROBLEMS THAT ARE IMMEDIATELY INTELLIGIBLE TO THE LEARNER, (2) FREEDOM FOR THE STUDENT TO PERFORM DATA-GATHERING OPERATIONS, (3) ACCESSIBILITY TO ALL DATA, AND (4) A SHIFT OF MOTIVATION FROM "DESIRE TO BE RIGHT" TO THE DESIRE TO "FIND OUT WHY." (FM)

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UNIVERSITY OF ILLINOIS

THE ELEMENTARY SCHOOL TRAINING PROGRAM IN SCIENTIFIC INQUIRY

BY J. RICHARD SUCHMAN

ASSOCIATE PROFESSOR OF EDUCATION, PRINCIPAL INVESTIGATOR

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THE ELEMENTARY SCHOOL
TRAINING PROGRAM
IN SCIENTIFIC INQUIRY

by

J. Richard Suchman
Principal Investigator

June 1962

PREFACE

A defensive posture is generally not conducive to creativity. When man's very survival is threatened he tends to throw his energies into rigid and stereotype modes of solving the problems that threaten him. Sputnik precipitated a crisis in American education that has in many ways been met with just such a reaction. It is a curious paradox that when we need so desparately to capitalize on the creative abilities of our citizens to generate wholly new solutions to the new problems of our time there is greater pressure than ever to put the curriculum above the learner, to minimize individual potential or creative thinking in favor of building higher levels of proficiency along prescribed and currently valued lines.

Has our preoccupation with knowledge and achievement blinded us to the importance of the means by which knowledge comes into being? New knowledge is the result of inquiry, and if our pupils are to be more than simply the consumers of knowledge, we must prepare them to inquire productively, combining bold, creative thinking with the rigor of logical analysis.

The Illinois Studies in Inquiry Training has been a continuing research program since 1957 devoted exclusively to exploring the means of building inquiry skills in young children. This report represents the culmination of five years of work on the development and evaluation of a technique by which teachers can make inquiry a regular classroom activity.

Like most research, this has been a cooperative venture which has benefited from the talents and ideas of many persons both on and off the project staff. I wish to acknowledge with appreciation the help of the following people who have made substantial contributions to our research efforts:

My thanks go first to the twelve teachers who spent eight weeks in Urbana as "the trainees" and who then brought Inquiry Training into their respective schools. These were not passive learners; they gave to the summer workshop as much as they took from it and added new strength to the Inquiry Training program. They are further identified in the body of this report but here are their names: Warren C. Coffey, John Cunningham, Edward J. Eaton, Eugene Irving, Frederick Kline, Roland J. McAnulty, John S. Palumbo, Carl Renshaw, Norval Scott, Robert Sheldon, and Fred Wilkin.

Over the three year period a total of seven graduate students at the University of Illinois served as research assistants. Each in his own way made important contributions but space does not permit an elaboration of these. Their names are: Terry P. Denny, James L. Fejfar, Helene Henry, Kenneth Peiser, T. V. Sathyamurthy, Sheldon Siegel, and Leone Smith. Sybil Baltis Carlson, an NDEA Fellow, served her internship during the 1961-62 school year on the project staff. Emanuel Lask, also a graduate student at the University, served as research associate from September 1960 to the termination of the project in June 1962 and in this capacity supervised much of the test construction and data analysis operations. For a six-month period in the middle of the project Dora Damrin, then a Research Assistant Professor in the College of Education, worked as a special consultant on measurement problems.

Among the University of Illinois faculty who lent their time, interest, and wisdom as consultants and advisors were: Myron Atkin, David P. Ausubel, Harry Broudy, Roger Brown, James J. Gallagher, Orrin Gould, J. Thomas Hastings, Gertrude Hendrix, David Page, Sidney Rosen, Robert Spaulding and Lawrence Stolurow all in the College of Education. Rupert N. Evans, Dean of Administration in the College and formerly Research Coordinator, is due a vote of thanks for his ceaseless efforts in easing the administrative burden of the project director in countless ways and for his advice in the preparation of the original proposal.

Charles P. Slichter and James H. Smith, both of the Physics Department of the University of Illinois generously gave of their time to appraise the physics content of the films and the resumes.

A large number of persons not on the University of Illinois campus were consulted one or more times regarding a wide range of problems. Chief among these were: Paul Brandwein, Harcourt, Brace & World; Jerome S. Bruner, Harvard; Elizabeth Drews, Michigan State University; Francis Friedman, Massachusetts Institute of Technology; Ray Hyman, General Electric; Jerome Kagan, Fels Research Institute; Robert Karplus, University of California, Berkeley; Esin Kaya, New York University; Fannie Schaftel, Stanford University; Joseph Schwab, University of Chicago; Irving Sigel, Merrill Palmer Institute; and Hilda Taba, San Francisco State College.

There were many others who in private conversations and correspondence affected the course of our research and share the credit for whatever success we have had. Since I should never be able to recall them all, rather than slight those who are inadvertantly omitted, I shall thank them as one anonymous group.

Eileen Tobey, project secretary, deserves special mention for her many hours at the keyboard retyping successive revisions and for the efficient manner in which she carried out the variety of tasks assigned to her.

Last and by no means least I should like to acknowledge the support of the Educational Media Branch of the U.S. Office of Education for its financial support through the National Defense Education Act. Members of their staff cooperated in many ways to help bring this project to fruition. I am equally indebted to the Graduate Research Board of the University of Illinois for its early and continued support of our work.

J. Richard Suchman
Urbana, Illinois
May 31, 1962

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CHAPTER I

INTRODUCTION

The purpose of this investigation has been to develop materials and procedures for teaching the skills of scientific inquiry to elementary school children. Inquiry is a way to investigate causation. Regardless of what is being investigated and at what level, there are certain fundamental thought processes of inquiry that are essentially the same. What are the possibilities of improving a child's general ability to inquire productively by developing these thought processes?

How people think when they inquire seems to depend partly upon the kinds of thinking experience they have had. Bruner (1958) reports that people tend to organize their search for new ideas according to patterns they have found successful in the past. In a sense, they develop a style of thinking which they use in a wide range of problem-solving situations. The more practice a person has in inquiring and discovering, the more extensive is his reserve of productive thought models.

But are there certain styles of thinking that are generally more productive than others? Inhelder and Piaget (1958) report that children go through a set of progressive stages in the way they think while they are investigating causal relationships in physics problems. These authors stress the significance of operational thinking which has its onset about the time the child first enters the elementary school. Concrete operations are manipulations of the environment which can be reversed, *i.e.*, done and undone. They form the basic unit of data gathering. This ability to make limited and tentative changes in the environment and to observe the consequences enables a child to experiment with isolated variables. Concrete operations are performed to bring to light properties of the environment, and to provide an empirical basis for the conceptual ordering of objects and events.

Concrete operations are replaced gradually by formal logical operations, in which propositions are tested for their logical compatibility with existing conceptual structures. While there still may be an appeal to empirical evidence to test a proposition, the idea is first tested logically. Thus formal logical operations may be wholly internal, or they may include highly selective data-gathering as a kind of validity check for the logically derived conclusions. Inhelder and Piaget challenge educators to explore the possible means of accelerating growth from concrete to logical thinking. To make this transition one must be able to think in terms of logical structures (e.g., variables, categories, relationships). And in order to make any use of logical thinking one must be able to transpose data into logical systems and vice-versa. The obvious advantage of logical operations is that the results have broad application to entire classes of events. The findings of concrete operations are specific only to the actual conditions tested.

Dewey suggested that logical thinking would result from encouraging children to use the "scientific method" in school. He knew that people tend to view objects and events in a more or less total way, and that these total perceptions (Gestalts) can be misleading. By breaking the percepts down, one can identify a set of variables, manipulate them experimentally, and determine how they are related to each other. In promoting the use of the scientific method, Dewey saw the means of preserving in the child his natural virtue of curiosity.

But can there be strategies of inquiry that transcend the boundaries of a single discipline? Can we, as Dewey suggested, teach broad search models that are appropriate for a range of inquiry problems? Conant (1947) denies that there is such a thing as the scientific method, suggesting instead that there are many "strategies and tactics" of scientific thought. He points to the fact that the great conceptual breakthroughs in the history of science were brought about through a wide variety of accidental and deliberate operational schemata. He proposes that many of these strategies and tactics can be taught to college students through case histories of scientific discovery. Looking over the shoulder of Lavoisier the student could then follow along through the series of errors and insights that led ultimately to his theory of combustion.

But what is to be gained by reliving the cognitive strategies of others, no matter how great the historical consequences may have been? Certainly this might convince the student of the diversity of the pathways to discovery, but to invent and employ strategies appropriate to each new problem as it arises would seem to require more than a catalog of heuristic models. In the Inquiry Training program we have tried to create a technique that enables the individual to develop his own strategies and the ability to select and alter them in accordance with the problem at hand.

Our purpose in Inquiry Training has been to help children develop a set of skills and a broad schema for the investigation of causal relationships. We have tried to teach children to gather and organize data, to isolate variables, to hypothesize relationships between variables, and to test these hypotheses through verbalized experiments. It was our expectation that by this training we could make it possible for elementary school children to have greater autonomy in their own conceptual development.

Our rationale was as follows: (a) Learning through inquiry transcends learning which is directed wholly by the teacher or the textbook; the autonomous inquirer assimilates his experiences more independently. He is freer to pursue knowledge and understanding in accordance with his cognitive needs and his individual level and rate of assimilation. (b) Inquiry is highly motivated because children enjoy autonomous activity particularly when it produces conceptual growth. (c) Concepts that result from inquiry are likely to have greater significance to the child because they have come from his own acts of searching and data processing. They are not just abstractions that have been structured by the words of other people. They are formed by the learner himself from the data he has collected and processed himself; and for that reason should be more meaningful to him, and hence more stable and functional.

In a series of pilot studies we determined that small amounts of certain kinds of training had the effect of changing the way children went about asking questions in search of causal relationships. In one of these studies children who received as few as four hours of special training were able to ask nearly three times as many questions under test conditions as those who had not been trained. Furthermore, there were indications that the questions asked by the trained groups were superior in their design and organization to those asked by the untrained subjects.

The methods and materials used in these pilot studies were designed for research purposes only and required considerable revision before they could be applied under ordinary classroom conditions. The present study has been devoted to their further development and to the equally important job of giving Inquiry Training a trial under varied classroom conditions so that a more realistic evaluation of its effects might be obtained.

CHAPTER II

THE STRUCTURE AND FUNCTION OF INQUIRY

Inquiry can be divided into four main types of action: searching, data processing, discovery and verification. While none of these actions is unique to inquiry, they are all essential to it and, in combination, form a cycle of operations that characterize the inquiry process.

Searching

Inquiry involves taking in and processing data. Data provide raw material from which concepts, generalizations, ideas, etc. are abstracted. It is possible to obtain data by just taking note of whatever happens without performing any active analysis. With this approach the observer's perceptions are likely to be strongly influenced by the more external and salient characteristics of the data. Little autonomous action or control by the learner is required.

When the intake of data is planned and controlled by the observer, we have the act of searching. The idea of the search is to bring in information of a particular kind, at a particular time, and in a particular sequence in order to derive the maximum value from it in the formation and evaluation of ideas. Searching is an active and aggressive cognitive function. It increases and focuses the flow of data which gives the inquirer the informational resources he needs in the formulation of new ideas. In addition, it permits the inquirer to program his data intake to satisfy his informational requirements at any given moment in the process of concept attainment.

There are several characteristics of searching that make it more productive of new data. The first of these is mobility. The idea of moving about and shifting attention is basic to our concept of search. One tries to expose himself to a wide range of data sources. The more territory he covers, the more sources of data he finds and the greater his chance will be of finding whatever it is he is searching for.

The second characteristic is manipulation. To the extent that we can control environmental conditions and alter them in some systematic way, we can observe the effects of these changes on other conditions. In this way it is possible to increase the yield from some sources of data.

The following example illustrates the effects of mobility and manipulation on data flow. A paper-clip is lying on a table in front of me. The most passive thing I can do is to pay no attention to it at all and wait for the object to impinge upon my consciousness. Knowing paper clips as I do, I seriously doubt that this course of action (or inaction) will result in a single datum. Becoming more mobile, I might glance around until I was looking at the clip, taking note of its color, size, shape, texture and position. My mobility would become greater as I touched the clip to sense its weight, texture, temperature. From these data, against a background of experience with many objects and materials, (assuming I had never seen a paper clip before) I could make a number of inferences about the properties of this object. Its color and texture would suggest that it was made of metal. If most metals in my experience had been malleable, I would probably assume that the clip could be bent without breaking. But to verify this assumption I must observe a paper clip that has been subjected to a stress that is great enough to produce bending; I must see the clip under a new set of conditions. For this purpose, manipulation will serve me well. I simply create the desired condition and observe the results. The new data produced add to my collection of data that bear on the properties of paper clips and other related objects and materials. In general terms, activity increases data intake. Mobility extends the perceptual range of the observer exposing him to new sources of data. Manipulation produces more data yield from a single source.

The activity described above is a necessary but not a sufficient condition for search. The searching organism must also have (a) a domain in which to operate - a place to search in, (b) freedom to move within this domain, to decide in what direction to move at each choice-point, (c) a "set" to guide the selective procedures, to enable one to differentiate and evaluate data in terms of his goals, and (d) an overall system or plan (it may not be a conscious one) to guide the sequence of search operations. Although random plan-less search is theoretically possible, it is doubtful whether any human behavior can be wholly random. Of course, deliberate attempts to act randomly are planned actions in themselves.

The search "set" deserves some elaboration here because of its importance and complexity. Almost all animal forms have sensory apparatus and neural mechanisms that permit them to attend selectively to certain classes of stimuli while screening out others. In other words, they are able to keep the perceptual intake variables reduced to a number and to types which they can effectively handle in their data processing systems. In lower forms of life much of this selection is built into sense organs themselves. In man, selectivity can be adjusted over an almost infinite range of possibilities. Sets involving all sense modalities and levels of abstraction can be learned and used in the act of searching. Several sets can be operating simultaneously, separately and in combination. Take the game of solitaire, for instance. As we search through the pack we keep in mind five or six sets for cards that are needed on the board, a red three, a black queen. At the same time we are alert to developing possibilities for moving a black seven to another spot in order to free the eight of hearts which is next in line on the hearts pile. But few people ever notice that two of the jacks in the deck are in profile and two are looking at you head on, although these data are as readily available as the spots and numbers. (There is a variety of poker in which the number of eyes on the jacks is a critical variable, and in this game, even those who are playing it for the first time become immediately sensitized to the difference between one and two-eyed jacks.)

But the differential awareness of stimuli is not the whole picture with regard to set. We can learn sets that alert us to abstractions. A child can pick out the "ugly" face from a set of pictures he has never seen before, or choose the "middle-sized" object from a group of three. An adult can sense which of several solutions to a problem is the most elegant. We have, in fact, a great many sets in our everyday searching that we are not even conscious of, let alone able to define. A woman shopping for a new handbag may have a number of conscious evaluation criteria, yet be unaware of the "sets" that mediate the way she responds to the available cues in making her decision.

The ability to respond to abstract patterns adds tremendous flexibility to the process of search. The same data can be processed and reprocessed a thousand times, and as long as the searching sets are constantly readjusted, new findings emerge. The yield of any search is as much a function of the richness and variety of sets employed as it is of the richness and variety of data. Much depends of course, on the goal of the search. If one is looking for one datum only, such as finding the location of a particular car in a large parking field, the set must be narrow and well defined. The number on the license plate would be sufficient. But if one were trying to find causes for the bad winning record of a football team, many data would have to be obtained and these would have to be examined and re-examined in the light of different hypotheses. And even then, there might be a number of causal factors all acting simultaneously. It is obvious that under these circumstances an abundance of sets is just as important as an abundance of data. Furthermore, the intake of data must be adjusted to meet the requirements for testing each hypothesis. It is not just a matter of how much data you get and how many ways you look at it, but also _whether you can get the data you need when you need it_.

The second example, that of finding the causes for the winning record of a football team, is much closer to the kind of search that occurs in inquiry than the first example of searching for a car in a parking lot. Inquiry is more than simply the search for an object that matches a set of criteria. Inquiry must involve the synthesis of ideational patterns. It is essentially, though not exclusively, inductive, leading from the specific and concrete to the general and abstract. The data obtained from the search process are used in the formulation and testing of conceptual patterns that correspond to regularities in the domain being investigated. The operations that promote discovery include not only the acquisition of data through search, but also the organization, transformation, storage and retrieval of data as well. For the sake of this discussion we shall include these latter functions under the broad category of _data processing_.

Data Processing

Information that is acquired through searching is not typically in a form that will maximize the probability of discovery. The ability to assimilate data within the framework of conceptual patterns depends in part upon the way the data are brought together and organized. Therefore, to bring about the greatest possible assimilation, the inquirer must process the data. The general aim of data processing is to reduce the information to simpler and more systematic patterns so that regularities (e.g., principles, relationships) in the data, if there are any, will be more discernable.

Four types of processing have major roles in inquiry:

1. Analysis - the breaking down of data complexes into their component parts.
2. Comparison - the bringing together of comparable elements to make similarities and differences more evident.
3. Isolation - the selective separation and attention to small groups of variables to reduce the cognitive strain that results from excessive diffusion of attention.
4. Repetition - the repeated juxtaposition of data elements to decrease the probability of unrecognized relationships.

Analysis.

Perceptions are organized patterns of stimuli (Gestalts) that are taken in as a unit. They are meaningful only to the extent that they correspond to patterns that already exist in the mind of the perceiver.

But no further meaning can be derived unless (a) the percept is compared with other percepts or (b) it is broken down into its component elements which can themselves be assimilated. The latter case is analysis. While a unique event can be recognized and identified in terms of an equally unique concept, it can only be understood in terms of concepts that have application to other events as well. Thus, we try to understand the specific and unfamiliar in terms of the general and familiar. In this way we have a means of relating one unique event to another, and from the systematic study of relationships we derive our ideas of causality.

The difficulty in analysis is the very strong tendency of people to respond to objects and events in terms of perceptual wholes (syncretism). This is particularly true of persons who have not conceptualized the variables or categories necessary for performing an analysis. Thus young children are more vulnerable to perceptual domination than older ones, and in general, people with a broader conceptual base are better equipped to analyze than those who have not conceptualized the categories into which a perceived object or event can be broken down.

For example, at a very early age we become accustomed to seeing bubbles rising in a liquid. The young child has seen bubbles many times and recognizes them instantly. He knows that they rise and that they burst when they come to the surface. These properties are all part of his general concept which he has obtained perceptually, without analysis. But how could he ever learn what makes bubbles rise in a liquid without analyzing the event? And how could he begin to analyze the event without some such concept as "force" or in this case "pressure." In order to learn that the upward movement of the bubble was caused by the water pressure pushing upward with a greater force than water pressure pushing downward, he would have to either know that the pressure in a liquid increases proportionally with depth, or at least that water pressure was a variable that could be sampled at various depths. Having no concept of pressure or its relationship to depth in a liquid, the young child has no basis for performing the generally accepted analysis of the episode of the rising bubbles. He can generalize that bubbles in liquids always rise, but this is not an explanation.

We can help the child to analyze by helping him conceptualize new dimensions, variables, or categories which can be used for breaking down his syncretic perceptions. The possession of such concepts not only gives the child a way of analyzing what he has already perceived, but it serves to guide the searching process so that new data will be sure to include variables that have been useful in previous analyses. The identification of variables cannot be stressed too much. Inquiry is largely a matter of the manipulation of variables under controlled conditions in order to study relationships between them. But variables must first be isolated and identified before they can be experimentally changed.

Comparison.

One of the principles of associative learning is that stimuli that are presented in juxtaposition (temporarily or spatially) are more likely to become mentally linked to each other than are stimuli that are separated by time or space. For the purpose of discovering regularities of systematic variations in a set of concrete instances, there is an advantage to bringing the instances into the closest possible proximity to each other. The simple comparison of the size, color, or shape of two objects is far less difficult to make when both objects are in front of you at one time, and easier still if they can be held up next to each other. Thus, if the processing of data enables us to sort out dimensions which we would like to compare and to bring these data together, we are more likely to see the existing relationships.

A standard physics demonstration uses a brass ring and a brass ball which fits easily through the ring when they are both at room temperature. When the ball is heated over a flame it no longer can pass through. After the ball remains in contact with the ring for a while the former once again is able to pass through the latter. For children who are not aware of the effects of temperature on the volume of matter, these events pose genuine problems. However the juxtaposition of certain data increases the likelihood of the discovery of relationships. If the children are able to sample the temperature of the apparatus at different times during the experiment and can process their data by organizing it as displayed in Figure 1, the probability of discovery is increased:

Figure 1

Ball and Ring Temperature Chart

	Before heating	After ball is heated	When ball slips through again after being stuck in the ring
Ball	75°	150°	95°
Ring	75°	75°	95°

This could lead to the inference that when the ball is hotter than the ring it will not slip through, but when the temperature is the same it will.

But if this particular contiguous arrangement is the only one used the relationship between temperature and volume is not likely to be discovered. Figure 2 presents the temperature data for the ball in juxtaposition to the volumetric data, which are estimated by a reading of the diameter of the ball.

Figure 2

Temperature and Diameter of Ball

	Before heating	After ball is heated	When ball slips through again after being stuck
Temperature	75°	150°	95°
Diameter	2 cm.	2.2 cm.	2.1 cm.

Each new pattern of data grouping promotes the discovery of new relationships, and data which are so processed as to facilitate repeated reorganization and new comparisons will produce a higher probability of discovery than data which can be compared only in a single fixed pattern. In short, the comparison of variables increases the likelihood of discovering the relationship between them.

Isolation.

Causality is rarely a simple matter. The number of conditions that are necessary for even the simplest of physical or biological events in our environment can be staggering. The child searching for the "why" of these events can find himself very quickly in the midst of a tangle of variables, related to each other in very complex ways. The job of embracing at one time the interrelationships among all variables relevant to an event is more than most scientists attempt, except where their relationships can be reduced to mathematical formulas.

The child too must keep the data-processing load within the limits of his cognitive system. To maximize the probability of discovery, he should work with two or three variables at a time, manipulating one, observing the effects on one or two others, and holding the rest constant. If he tries to keep track of more than this, the cognitive strain may become too great for him to continue or his attention becomes too diffuse to enable him to learn anything with precision. In other words, the more variables one attends to simultaneously, the less likely it is that relationships among them will be discovered.

For example, a child is trying to find out why a bimetallic strip bends when it is held over a Bunsen burner flame. The strip is made of a lamination of unlike strips of metal (usually steel and brass) that have been welded together to form a single blade. With a handle at one end it has the appearance of a narrow knife or spatula. When this apparatus is heated the metal in it expands. But the rate of expansion is not the same in the two metals. Consequently, half of the thickness of this laminated strip becomes slightly longer than the other half, and since the two halves are attached to each other, the internal stresses force the blade to assume a curve of which the outer circumference is occupied by the metal which has expanded the most.

The child who encounters this problem must contend with the following variables: the temperature of the blade, the shape of the blade, the structure and composition of the blade, the length of the blade. These are all highly relevant to the problem at hand and the inquirer must sample them at various times during the demonstration to determine changes.

In addition, there are innumerable other variables which, although irrelevant to the bending, must be considered by the child before he can determine this fact. The position in which the blade is held during the heating, the composition of the handle, the source of heat, the upward pressure of the gas flame are just a few of the variables which concern the typical inquirer, but which do not affect the bending appreciably. If the child immediately tries to hypothesize complex relationships among all the variables that seem relevant to him, he could go on testing indefinitely without any noticable progress. But by isolating variables and testing them singly he can eliminate the irrelevant ones and discover the relationships that exist between each relevant independent variable (such as the temperature of the blade) and the dependent variable (which in this case is the bending of the blade).

Repetition.

Even some of the most obvious relationships are not recognized in the data at first. A single series of systematic manipulations of an independent variable may not lead to a discovery of how it and the dependent variable are related. This is particularly true when the relationship is non-linear or when there is an interaction between two independent variables. In such cases the repetition of events may be necessary for discovery. The inquirer in his searching activities can cover the same territory many times if he has difficulty discovering relationships at first. If he has already stored and organized these data, either in his mind or on paper, he can review it as often as he requires until the relational patterns become clear to him.

These are just four major functions of data processing that help assimilation and accommodation. As I have pointed out previously, the processing acts lead not only forward to discovery, but feed back also to reactivate and redirect the searching function. The perceptually oriented child tends to permit Gestalts to dominate his thinking (although adults are by no means immune to this type of bias). The autonomous acts of data processing give the inquirer a means of breaking out of some of his Gestalts and synthesizing from the analyzed data new concepts (accommodation) which in turn promote assimilation.

Discovery

There are moments in the process of inquiry when one sees things suddenly fit together. This experience has been called "discovery," "insight," "aha," "illumination," and other names which imply sudden understanding that has highly pleasurable if not exciting overtones. While there may be a great deal of similarity in the subjective aspects of such experiences, there seem to be several rather distinct kinds of cognitive activity that lead to this feeling state. The so-called "act of discovery" may be any one of a number of acts which yield, as an end product, a higher degree of assimilation than was possible prior to the act. We spend most of our waking hours perceiving objects and events that are so familiar to us that their assimilation is hardly noticed. When one looks into the mirror he does not experience "discovery" upon seeing his face. The feeling of discovery occurs only when a discrepancy or dissonance between what is perceived and what is known or believed first blocks assimilation and then is overcome by some cognitive act. This can come about in several ways. Analysis may reveal familiar elements in an unfamiliar configuration of data. A percept may not be assimilated in its total form because the perceiver does not have the appropriate concepts.

But, when the percept is analyzed into component parts, some of these can be handled by a conceptual system of the perceiver and assimilation begins to take place. This is nothing more than translating the unfamiliar into familiar terms. It is one of our chief modes of effecting assimilation.

Sometimes the experience of discovery comes as a result of matching two concepts. The collection and processing of data make it possible to see patterns or regularities. Sometimes one finds a kind of "match" between these patterns and those already drawn from previous experience. The recognition of this match may also give rise to the experience of discovery.

A third avenue to discovery comes as the result of a conceptual shift. There are times when an inquirer finds no way of accounting for a perceived event in terms of his existing conceptual systems, even after a systematic analysis of the event. In such cases the problem may stem from the fact that his conceptual systems are simply inadequate to permit assimilation. If, on such occasions, the inquirer is given an adequate system for this purpose by somebody else (presumably through verbal communication) or he is able to adapt some old system to make it adequate, or he is able to invent a new system, assimilation may be the result and the inquirer may feel as though a discovery has taken place.

Discovery then can be thought of as the experience associated with the sudden assimilation of perceived data within the framework of a conceptual system regardless of whether this was brought about by a reorganization of the data or of the system.

This view of discovery is presented here more as an hypothesis than as an explanation. In later chapters as the details of the inquiry method are given, it will be obvious to the reader that Inquiry Training is directed almost exclusively toward strengthening the process of analysis and the eduction of relations. There is no attempt to teach children how to invent or adapt conceptual systems. This is a far more creative activity for which there are no set procedures that can be taught. But there are conditions which we believe enhance creative thinking of the kind that leads to adaptive conceptual reorganization. These conditions are (1) freedom to gather data and test hypotheses, (2) maximum and rapid feedback from each data gathering operation, and (3) absence of externally applied pressures or rewards (i.e., motivation inherent in data processing and discovery). These conditions permit the child to be led by his cognitive needs and to learn through trial and error what strategies work best for him.

Verification

The construction of a valid conceptual system requires testing to determine its soundness. This is done by going back to the level of concrete instances to see whether the system permits the assimilation of the data it is supposed to. Can it be used to make reliable predictions? Does it explain all relevant cases without exception?

If a child through his conceptual systems predicts that the bimetallic strip will operate in reverse when the temperature is lowered below room temperature, a deductive test of the prediction and the system would be to place it in a freezer to see.

Conceptual systems that do not hold up under empirical testing must be restructured before they can fully accommodate the data. The cyclical process of restructuring concepts, and verifying them empirically until they are found to need further modification is repeated over and over again in the inquiry process. In short, verification puts a check on theory building, preventing it from getting too far from reality.

CHAPTER III

INQUIRY TRAINING

Inquiry Training was conceived as a way to help elementary school children comprehend the logic of inquiry and to give them practice and guidance in searching for systematic relationships in physical phenomena. The main emphasis is on the strengthening of autonomous processes. We put children in a position where they can learn only through self-initiated and self-implemented quests for information. A problem is posed in the form of a motion picture of a short physics demonstration. The children are confronted with the question "Why?" They must search for what they need in order to piece together an explanation. They may obtain additional data from the teacher by asking questions, but they may not ask for generalizations or explanations. They must formulate their own hypotheses and test these with questions that take the form of verbalized experiments.

Explanations are Based on Concepts

Explaining the causation of even the most simple physical event can involve some broad, basic concepts. Take, for example, the bimetallic strip described in the previous chapter. The explanation that the strip bends because it is heated is obviously not adequate. There are many objects that do not bend when heated. Nor could one fully explain the phenomenon in terms of the structure of the strip. There are many objects made of laminated materials that do not bend for this reason alone. No single condition in the episode can be labelled as the cause of the bending. Nor is the enumeration of all the conditions of the episode an explanation either. Some of the conditions are quite irrelevant to the bending. Take away the wooden handle of the blade and the object still bends when heated. Replace the Bunsen burner with a candle and the outcome is essentially unchanged, except for the rate and degree of bending.

Explanations should relate the specific to the general. The bimetallic strip in the episode bent because the conditions created in the demonstration met the requirements for such an event to occur. In terms of Newtonian physics, the bending was a form of motion. Since the strip was not in motion before it was heated, there was an acceleration. For an acceleration to take place there must be a condition of unbalanced forces. Within the Newtonian conceptual system an explanation of the episode must concern itself with forces and the conditions that altered their balance. An analysis of the episode would be an attempt to determine what forces were present and how the imbalance was achieved.

In the case of the bimetallic strip, the forces were stresses produced within the strip by expanding metal. Half of the strip was expanding more rapidly than the other half. As the lengths of the two halves were becoming more disparate, and the two remained bonded together at a common surface, the relation between then had to change from that of parallel lines to that of concentric circles, which accounts for the bending.

But how does the increase in temperature cause the metal to expand? What causes matter to occupy more space when it is hot than when it is cold? The pursuit of these questions can lead to the concept of molecules, molecular motion and heat conductivity.

The analysis and explanation of the bimetallic strip does not need to remain circumscribed by the dimensions of the immediate episode at hand, nor does the conceptual system have to be Newton's. Since an explanation is an attempt to relate concrete events to general principles within some conceptual system, every problem episode has a wide range of possibilities for analysis and explanation. One can pursue the explanation of a single concrete event to increasingly high levels of abstraction by shifting to broader conceptual systems as the basis for the explanation.

Inquiry and Conceptual Growth

Through the inquiry process information is collected and processed to facilitate the analysis of perceived phenomena and the expansion of conceptual systems. The analysis is meaningful only in terms of a conceptual system, but the conceptual system may be expanded and reorganized as a result of the analysis. This dual process of (a) interpreting data in terms of pre-existing concepts and (b) modifying concepts to correspond to the data, is what Piaget (1950) calls assimilation and accommodation. These two functions are central to conceptual growth, and Inquiry Training is largely a matter of helping children learn to perform them more autonomously and productively.

Assimilation is the ordering of percepts in terms of existing conceptual structures. Once again using the bimetallic strip as an example, the child sees a long thin flat metallic-looking blade with a wooden handle. These percepts roughly match the child's concept of "knife" even though the object does not have a pointed end or a sharp edge, and has not been seen used for cutting. The child has assimilated the data through his concept of knife. Once this has taken place the object may be regarded as though it were a knife having other properties generally attributed to knives. Thus, assimilation makes it possible for the learner to use what he knows (or believes) to add meaning to what he perceives. Of course, once he sees the blade bending upon being heated, he may reject the "knife" assumption. This leaves the episode unassimilated once again.

But what happens next? Is assimilation then impossible? The answer, of course, is "no." Even a new whole can be made up of many familiar parts. Once the child has determined that the bending of the bimetallic strip cannot be attributed to melting and drooping, he generally finds that the event as a whole cannot be assimilated. If he turns to the analysis of the object or of the event, he learns perhaps that the blade is made of two laminated strips of metal, one steel and one brass. Now he can assimilate part of the demonstration. He already has certain concepts about these metals. Perhaps he knows that they both expand when heated, but at different rates. If he analyzes the event he may find that the metals were the same length before the heating but different lengths after heating. He may suspect that the metals were unlike and expanding at different rates. In any case, analysis facilitates assimilation.

Whenever a person encounters an object or event that he cannot assimilate even with the help of analysis, he must restructure or expand his concepts before his unassimilated perceptions can become meaningful to him. This process of altering concepts to fit new perceptual patterns is accommodation. When data are collected for the purpose of discovering new relationships among variables or for extending knowledge of the properties of an object, this aspect of cognition results in new conceptualizations that extend the possibilities for assimilation.

Assimilation and accommodation work hand in hand. In the process of inquiry the learner shifts back and forth from one to the other, assimilating data, modifying his conceptual systems to accomodate to the data where necessary, assimilating more data, and so on. Failure to accommodate prevents conceptual growth. Diehard assimilationists never grow conceptually. If a child persists in trying to understand the bimetallic strip only in terms of the melting or softening of metals, without ever considering other properties, he will never find a satisfactory explanation, nor will he expand his conceptual system. Excessive accommodation, on the other hand, produces a constant procession of conceptual changes to accommodate each new perception. A different system is used to assimilate each new episode. This results in a proliferation of ideas, none of them broad enough to assimilate more than one episode. Concepts formed under these conditions would have very little generality or power.

But effective shifting requires a certain awareness of the strategies of inquiry, and of its structure and goals. There must also be a set of skills, which can come only from experience. Good inquiry is not innate; it must be learned and practiced.

Inquiry Can Be Learned

When two or more experiences give rise to an idea or concept that represents a relationship between them, a discovery has taken place. But discovery is not inquiry. Discovery is a sudden awareness that occurs under certain conditions as described in the previous chapter. Inquiry includes the acts of search and information processing that provide many of the necessary conditions for discovery.

Inquiry is used by infants without any special training, but we do not know the degree to which their search patterns are biologically determined. The rooting response by which the infant finds his mother's nipple in the nursing situation is an example of search behavior. The infant also searches with his eyes and hands to find the exciting stimulus changes he seems to hunger for. Neurological structures may account for some of this patterning, but trial and error learning is probably a factor, too. As the infant grows up his behavior becomes less patterned by his biological structures and more by his experiences. His ways of searching and processing data can be made more productive and efficient by trial and error learning and eventually by guided learnings. Before a child is able to ask his first question, he is already learning some of the skills and strategies that will help him to make autonomous discoveries.

The possibility that the elementary schools could do more than they are doing to promote inquiry skills was brought sharply to our attention in the course of our pilot studies (Suchman, 1961). Children made curious by a puzzling episode and given freedom to ask questions were generally unable to inquire systematically or productively. They were shown a physics demonstration and asked to try to discover why the events occurred as they did by asking questions structured for a "yes" or "no" answer. The analysis of the protocols showed that the children tended to have three types of difficulty:

1. Low Productivity: In view of the amount of information needed and the amount of time and freedom provided for asking questions, the number of questions asked was remarkably small. The questions that were asked were generally unrelated and consequently did not pursue any idea to the point where they resulted in a useful analysis of the episode or the modification of conceptual systems.
2. Low Autonomy: The children's questions showed little evidence of organization or planning. There did not seem to be any kind of strategy in use. Consistencies from question to question

reflected stereotypes of question-asking form and structure rather than any underlying objectives. The questions seemed to result from whatever occurred to the children at any given moment rather than from advance decisions. One did not get the impression that the children were in control of the situation, that they knew what direction they were going or what means they had for getting there.

3. Lack of Logic and Precision: It was clear that the children lacked a functional understanding of the essence of experimental design and the rules of logical inference. Their questions were long and rambling, loosely constructed, and, in general, lacking in the precision and control that is necessary to obtain clear precise answers. "Yes" or "no" answers are meaningless or misleading if the questions are not carefully constructed to avoid equivocation. The children made a great many assumptions without ever being aware that they were doing this. Some objects and events were verified and others went completely unnoticed. As a result, the children were raising and testing hypotheses without the complete knowledge of all the relevant data. Valid explanations were nearly impossible to induce.

It was apparent from these studies that the children needed more than a search strategy. Their concepts of physical causality were narrowly structured and oversimplified; their attempts at inquiry were inhibited by a lack of self-confidence. Their goals were poorly defined, they were not certain how to achieve them, and had no history of successful search. It seemed that they were blocking because they didn't know what they could do when they were confronted by an event they could not explain. In the past they had customarily turned to the teacher or some other authority for explanations. They had learned to depend on others to structure their concepts for them. They had accepted uncritically most of what they had been taught. They had been given explanations they believed to be satisfactory, but which in fact they did not always understand. They had been given words but not necessarily concepts. Because they could repeat the words, they thought they understood. They were satisfied that they understood. In short, they relied heavily on the thinking of others and had not developed their own thinking abilities as much as they might have. With these difficulties in mind we undertook to plan a program of Inquiry Training.

The Program of Training

Objectives.

From the outset, the program was conceived as having three broad objectives, (a) to develop the cognitive skills of searching and data processing and the concepts of logic and causality that would enable the individual child to inquire autonomously and productively; (b) to give the children a new approach to learning by which they could build concepts through the analysis of concrete episodes and the discovery of relationships between variables; and (c) to capitalize on two intrinsic sources of motivation: the rewarding experience of discovery and the excitement that is inherent in autonomous searching and data processing (Hunt, 1961). We wanted Inquiry Training to consist of activities that were for the most part autonomously controlled and intrinsically rewarding.

While these objectives might appear somewhat ambitious for one project, we were already convinced from the pilot studies that they were in some measure achievable. We felt sure that (b) and (c) would be the natural consequences of (a). The three objectives are part and parcel of the entire idea of self-directed search and discovery. Once a person knows how to obtain the information he wants and how to use it to derive the conceptual structures he needs, he is in a better position to assume a new degree of control over his own concept development.

Key Elements of the Program.

The Problem Episode. In order to capitalize as much as possible on the children's initial inquiry skills and strengthen what had already begun to develop, we had the children start inquiring at once. To do this we placed them in a situation where the goal was to "find out why" and the means of attaining the goal was some form of inquiry. The children were confronted by an episode to explain, or in other words, a series of discrepant events to be assimilated. We used short physics demonstrations as the problem episodes. They were recorded on motion picture film and accompanied by a title which simply asked why a particular outcome of the demonstration had resulted. For example, with the bimetallic strip the question was: "Why does the object bend and then straighten out again?" The question converts the episode into a problem. "Finding out why" meant relating percepts to concepts.

We selected physics as the content area because the problems were somewhat circumscribed and they involved a reasonably small number of significant variables. Furthermore the episodes were intrinsically interesting to the children partly because the concrete form in which they were presented made them immediately intelligible, and partly because we selected episodes that had such surprising outcomes that it would be difficult for any child to remain indifferent after seeing the film.

Thus, the problem episode sets the stage for inquiry by defining an area of concern, by providing a perceptual experience, a goal to shoot for, and stimulating a desire to attain it.

The Responsive Environment: A responsive environment is a necessary condition for inquiry. The inquirer must be able to obtain data from his surroundings, and he must have the freedom to search and gather data in accordance with his informational needs. To the extent that the information is presented in a form or sequence that is not controlled by the learner, the process becomes something other than inquiry. In the course of Inquiry Training, the teacher assumes a new role. He stops "teaching" and starts responding. He stops structuring concept development for the child and starts facilitating discovery by the child. By giving the child more of a chance to employ autonomous search and data-processing the teacher helps him learn to perform these operations with skill and confidence.

In answering the children's questions the teacher does impose certain limitations. First, the questions must be so structured as to be answerable by "yes" or "no." This eliminates all open-ended questions and forces the children to focus and structure their probes. In a sense, each question becomes a limited hypothesis. For example, the child may not ask: "How did the heat affect the metal?" but he may ask: "Did the heating change the metal into a liquid?" In the first instance the child does not state specifically what information he wants. He is asking the teacher to conceptualize relationships for him, to teach him something. This is the very antithesis of what Inquiry Training is designed to do.

The second example is a request for information. In a laboratory the child would theoretically be able to obtain the answer himself through careful observations or experimentation. But in the Inquiry Training session we bypass the concrete laboratory operations by allowing the child to obtain the same kinds of data verbally. We are not concerned here with the development of laboratory techniques, but wish to free the child for a time from the distraction of such problems to enable him to devote all his attention to the strategies and tactics of searching and data processing. And by gathering his data verbally he is much less limited in the kinds of data he can obtain and the rate at which he can obtain them. In his experiments he can manipulate conditions quickly and efficiently without having to employ complex apparatus. He can produce conditions that would be totally impossible in the ordinary classroom. Such questions as, "Would the same thing happen if the apparatus were placed in a perfect vacuum?" or "If you put a glass of water in orbit so that it was weightless, would a cork float on the water?" are both excellent verbalized experiments, and verbally is the only way a sixth grader would ever be able to perform them.

There are other reasons for the verbal medium for Inquiry Training. The child who is working directly with laboratory apparatus is getting his data directly from his own observations. He "ask questions" by actually performing experiments and noting the results. But the teacher is left out of the picture because he has very limited access to information the child is getting and cannot begin to know how the child is using it in drawing inferences. Under these conditions the teacher has only indirect and unreliable ways of following the inquiry process of the child, and is thus handicapped in determining what kind of guidance to give the

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processed and toward the procedures by which such ingestion and processing are accomplished. In Inquiry Training we try to build a conceptual structure about inquiry itself, so that the child can plan his searching operations in advance, develop strategies that will increase productivity, and be able to evaluate and improve his own inquiry.

This cannot be done by simply talking about inquiry in abstraction. The recognition of the elements of process must grow as an increasing awareness in the child of just what he is doing when he tries to find out why something happens. We help him learn to analyze his own and other people's inquiry in terms of its structure and function. We give him first (a) many opportunities for guided practice in the use of inquiry, and then gradually help him to conceptualize (b) a structure for the analysis of causality and (c) a schema for the investigation of causal relationships. The purpose is to superimpose on the child's intuitive approach to searching a systematic and logical scheme, to make discovery the result of planning more than luck.

Guided Practice. Becoming aware of process and making it more schematic and logical are not changes that come about quickly in elementary school children. They come partly from the verbal structuring of the teacher and partly from the trial-and-error experimentations of the child. Neither is sufficient in itself. Each complements the other in the course of Inquiry Training. For example, the teacher cautions the children very early in the training that there is merit in analyzing the problem episode before determining relationships between variables or testing complex hypotheses. While it would seem to be the obvious thing to verify the parameters of the filmed demonstrations before trying to discover what produced the results, children typically resist this preliminary phase.

But by omitting this step and going right into experimentation they make a great many assumptions. They assume that they have perceived accurately every object, condition, and event that is relevant to the problem. In many of their everyday experiences children can get by with such assumptions, but with Inquiry Training films the failure to verify the parameters of the demonstration leads the child up blind alleys.

In the guided practice of Inquiry Training the children are permitted to make such mistakes in strategy, but the teacher sees to it that when the child runs into difficulty as a result, the source of his trouble is made clear to him. The teacher reviews the children's operations with them to help them see which strategies and tactics are effective and which are not.

Our technique for putting the focus on process in a way that does not compete with the children's on-going inquiries is what we call "critique" sessions. Each inquiry session is tape recorded. Immediately following the session, or sometime later, the tape is replayed to the group. After each question the tape is stopped and the teacher discusses the merits of the question with the group. At this time the children are not preoccupied with gathering data and finding explanations. They can think about their past operation in the cold light of retrospect. The effect is very similar to that achieved by showing a football team the films of the previous game. When not caught up in the excitement of the game itself, the players can be more objective and analytical about their own actions and those of their teammates, and they are better able to understand and accept the comments and suggestions of the coach. If the coach tried to do this during the game, he could not expect to produce as much learning.

The teacher helps the children formulate rules and generalizations about the logical structure of causality and strategies of inquiry. Each time, the children check their performance against these rules. Against this background of very concrete experiences, revived and made immediate through the recordings, the children can begin to conceptualize the structure of inquiry and to see the shape of the strategies they are being urged to use, and the consequences of using them or not. With each session the children see more clearly the success they achieve by following this pattern which reinforces the use of these systematic and productive operations.

A Structure for the Analysis of Causality.

For anybody to undertake an inquiry into the causation of an event, he must first have an operational definition of what constitutes causation. He must know what kinds of information he will be looking for and how this information can be coordinated to produce the explanatory system he is seeking.

In Inquiry Training we do not teach in abstraction about a structure for the analysis of causality. Instead, we help the children abstract the structure themselves from the many inquiries they perform throughout the training program. The teacher helps the children learn to use the following structure in the analysis of problem episodes:

a. Objects: All matter that can be differentiated from other matter in the episode may be considered as an object. Air, water, a piece of metal, a cork, are all examples of objects. Objects do not have to be visible or directly observable in other ways. The only requirement is that they have substance.

b. Systems: These are interrelated assemblies of objects. It is often necessary to regard such assemblies as though they were a unit. The bimetallic strip is a system, and each of its parts is an object. We can speak of the properties of the parts individually, or of the instrument as a whole. Whether we think of an object by itself or as part of a system depends on our objectives of the moment.

c. Conditions: Objects and systems can usually exist in many forms and states without losing their identity. A piece of metal can be hot or cold, bent or straight, long or short, wet or dry. A bottle can be full of water or empty, open or closed, right-side-up or up-side-down. Conditions apply to both objects and systems. They are, by definition, the dimensions of objects that can be changed, regardless of whether or not they do change during the episode. The entire range of possible variation within a given dimension is, taken as a whole, a variable. A condition can be determined directly by observation or measurement, a variable is a construct abstracted from a series of changing conditions. It is only through the study of changing conditions that children can learn to identify new variables and their relationships to other variables.

d. Events: Events are condition changes. When the bimetallic strip bends, a number of events occur and the result is a set of new conditions. The strip as a whole changes its shape from a line to a curve; the temperature of the strip increases; the length, width and thickness of the blade change. These are all dependent events, that is, they result from events that are directly and arbitrarily introduced by the demonstrator as independent events. To produce an event, one must change some of the existing conditions to create a set of new conditions, and for each event to be produced there are certain conditions that are necessary. Thus, for any event, it is possible to determine empirically just what the necessary conditions are. This knowledge permits us to make predictions about events from a knowledge of present and future conditions. We can also produce events by changing conditions to the point where the necessary conditions for a given event have been created.

e. Properties: If you subject a piece of wax and an iron nail to the identical conditions which include a temperature of 300° F. two different events will result. This is an example of the fact that identical conditions produce different events in different objects. The nail and the wax are said to have different properties. Or, put in other terms, the necessary conditions for melting wax are not the same for melting iron. Our only means of making positive identification of objects or systems is by checking their properties. The more properties of an object we know the more events we can predict involving that object. If we know that air can be compressed rather easily and that when it is compressed its temperature and pressure both increase, we are in a better position to predict the direction of pressure and temperature changes in air when volume is manipulated. Children can determine many properties empirically through observation and controlled experimentation. By building up a catalog of the properties of objects and systems in an episode they can move closer to the explanation of the events of that episode.

A General Schema for Inquiry.

There is no formula for discovery. Inquiry strategies vary over a wide range. Most of Inquiry Training has been a matter of letting the children experiment freely with their own question structuring and sequencing. In the critique sessions we tried to call their attention to the consequences of their strategies without imposing a system on them that would limit their creative thinking.

Nevertheless, inquiry can be divided into broad phases which on the whole should be undertaken in a logical order simply because they build one upon the other. Failure to adhere to this order leads either to erroneous assumptions or to low efficiency and duplication of effort. We have tried to help the children recognize these phases and see the value of planning their questioning in accordance with the schema.

Phase I: Episode Analysis

(1) The first step is to perform routine checks on every object and system that can be differentiated. The purpose is to learn as much as possible about their properties. This may be done in two ways. One is simply to ask directly if the object is a such-and-such. This is a form of assimilation. A child might ask, for instance, if the blade of the bimetallic strip were made of metal. Once he has identified this object (the blade) as metal, he knows a number of its properties (strength, malleability, high melting point, etc.) Another approach is to determine properties directly by experimentation. "If I held this blade in water for a long time would it become rust colored?" "If you bent the blade into a slight curve would it straighten out when you let go?"

(2) The second step is to ascertain the conditions of each object and system at the beginning of the episode and after each new independent event. This introduces not only measurement or observation of conditions, but also the element of time and the changes in conditions that occur between two different points in time.

(3) The children learn to assemble their data on the blackboard in the form of an episode analysis chart like the one in Figure 3. Conditions are aligned in rows corresponding to an object or system, and in columns corresponding to each new independent event. This chart makes sequences and correspondences in events more easily recognizable. They simplify the comparison of variables and make the discovery of new relationships more possible.

Phase II: _The Determination of Relevance_. The first goal of inquiry at Phase II is the isolation of the relevant variables and necessary conditions. This strategy calls for the manipulation of one variable at a time while the rest are controlled. This is done by questions that set up imaginary experiments. That is, the child proposes "test cases." For example: "If the temperature of the knife had not been raised would it still have bent as it did?" When the results of the demonstration _are_ or _could be_ affected by these manipulations the variable is regarded as relevant. In this case if the temperature had been held constant, the blade _would not_ have bent, so the question would be answered "No." Thus, the child determines that temperature is a relevant variable though he may not yet know _how_ temperature and bending are related.

The second goal of phase II is the identification of _conditions_ that are necessary for the outcome of the filmed demonstration. Here again the data are gathered through a series of verbal experiments. The child can

Figure 3

Episode Analysis Chart - Film No. 18: "Bimetallic Strip

Objects/Systems	Conditions/Events At Start of Demonstration			After Blade is Held in Flame			After Blade is Placed in Water		
	Temperature	Size	Shape	Temperature	Size	Shape	Temperature	Size	Shape
Bimetallic Strip	Room Temp. (A = B)	Normal (A = B)	Straight	>Room Temp. (A = B)	>Normal (A > B)	Curved	Room Temp. (A = B)	Normal (A = B)	Straight
Metal A	Room Temp.	Normal	Straight	>Room Temp.	>Normal	Curved	Room Temp.	Normal	Straight
Metal B	Room Temp.	Normal	Straight	>Room Temp.	>Normal	Curved	Room Temp.	Normal	Straight
Tank of Water	Water Temp. = Room Temp.			Water Temp. = Room Temp.			Water Temp. = Room Temp.		

determine, for example, that the metal strip will bend if the temperature is raised or if it is lowered appreciably, and the greater the temperature shift the more the bending. This is one step further than the simple determination of the relevance of the temperature variable. We are closer now to the answer to the question, "Why did the strip bend?" Obviously one necessary condition for bending was a sufficient change in temperature. In the continuation of Phase II all the other necessary conditions would be determined in this fashion.

Phase III: The Induction of Relational Constructs. Discovering why all these conditions are necessary is the function of Phase III. Knowing the necessary and sufficient conditions for a given event, one can predict and control its occurrences. But to explain the event one must first discover what physical principles and relationships govern the changes that occur. Such explanations can be formulated only when relational constructs have been hypothesized, tested, and found tenable. In this case, one such construct was the relationship between temperature and volume in metals.

The productive thinking requirements at Phase III of inquiry are obviously far greater than those of the preceding phases. As in Phase II the basic operation is the experiment, but since relational constructs must first be hypothesized before they can be tested by critical experiments, the productivity of Phase III is largely a function of the scope and ingenuity of the hypotheses generated and tested. Intuition and creativity appear far more critical for optimal behavior in Phase III than in the preceding two but the prior successful completion of Phase I and II, because of the data they produce, is also important at this level of inquiry.

Actually Phases I and II are merely preparatory steps designed to reduce the number of variables the inquirer needs to concern himself with. Phase III is where the heuristics begin. There doesn't seem to be any patterning that can be prescribed for this part of the inquiry process. Here is where the individual brings to bear his existing conceptual systems in hypothesizing causal relationships and testing them. Here too is where conceptual systems are expanded through the dual process of assimilation and accommodation.

General Administrative Procedures.

This section describes the actual procedures used by the teachers employing Inquiry Training on an experimental basis as part of this project. There are undoubtedly many alternative methods of achieving the same objectives, and probably many of them are superior to those actually used. It should be understood that the purpose of this part of the report is to describe what was done and how the teachers were instructed to do it. A discussion of possible variations in method can be found in the concluding chapter.

The teacher's role: The teacher has three main functions in Inquiry Training. (a) He establishes and maintains the procedures of operation, (b) he makes new information available to the group, and (c) he guides the development of inquiry skills and strategies. It has been our experience that even highly qualified people who have been teaching for many years require a considerable amount of time and special training to take on the new role completely and effectively.

(a) Establishing and maintaining the procedures of operation. To assure a high level of pupil autonomy, the teacher directs only the initial structuring of rules for data gathering. Once these rules are understood and the children are able to operate within them, the teacher becomes "responsive" rather than directive while the children are inquiring. That is, he answers questions, or refuses to answer them, but generally refrains from giving direction to the children's searching, data processing, hypothesis formation or hypothesis testing. Even in the act of answering questions the teacher must be careful not to provide any more information than the children specifically demand in their questions.

There is a question-asking technique that children often try to use that we call "brain-picking." Question-asking is supposed to be a vehicle for data gathering and nothing more. But when a child asks, "Does the heat have anything to do with the bending?" he is asking for more than data. He is assuming that the teacher knows the physical relationships involved in the demonstration, and he is drawing on this knowledge rather than the data. He is asking the teacher to do some of his thinking for him. There was a time when we refused to answer all such questions and simply said, "How could you experiment to find that out?" However, we found that in the early stages of training this tended to block children who could not yet draw inferences from data or were not facile in designing experiments. We then changed this procedure to permit the teacher to give the vague answer that the question demanded, ("Yes, it has something to do with it.") and then to point out to the inquirer (perhaps during the critique) that much more useful information can be obtained by direct experimentation. The following example might be suggested: "If you put the blade in an oven instead of holding it over the flame, would it bend the same way?" or, "If you made the flame less hot, would the blade still bend the same amount?"

It is not always possible to give an unqualified "yes" or "no" answer to each question asked. Sometimes this is the case because the question is poorly structured. If two questions are asked at the same time and the answers are not the same, the teacher tells the inquirer to ask one question at a time. Frequently the child will try to determine the condition of an object without specifying the time he is concerned with. Since conditions can change, such questions can be impossible to answer. (Example: "Was the blade the same temperature as the room?") In such instances the child is asked to specify when he means. This failure to make clear exactly what object, event, or condition the question pertains to, and at what point in time, may indicate more than poor communication on the part of the inquirer. We believe that by having to ask questions with precision the children become more aware of the many variables involved in the causation of physical events. Also, the need to be concerned with more than one or two variables at a time places a higher premium on thinking which we would like to encourage and develop.

(b) Making new information available. Once the children are accustomed to the procedures of obtaining data, the supplying of information to the children poses no particular problems if the teacher has the information to give. There is no substitute for being familiar with the problem episode and having a firm grasp of the physical principles involved. This is particularly true when the children ask experimental questions in which they modify the conditions of the problem episode. If a child wants to know if air pressure is a relevant variable, he may ask if the bimetallic strip would bend if it were somehow heated in a vacuum. The answer is "yes," but to be able to give this answer the teacher must know what the relevant variables are and in just what way they affect the bending.

There are certain circumstances under which new information is made available even though it is not specifically asked for. There are certain conditions in the episode that are not noticeable in the film but which would be immediately identified upon close examination of the apparatus. There seems to be no point in requiring the children to stumble upon these through their questioning when there is a very small likelihood that this would occur. Therefore, when the questioning gets to the point where the children need this information it is given to them. The fact that the bimetallic strip is made of two metals is fairly obvious when the apparatus is observed, but this fact does not show up clearly in the film. Therefore, if a child asks, "Was the strip made of steel?" we routinely answer, "Partly." There are other instances when the child's question is broad and close to requiring a "yes" but technically requiring a "no," not because it involved an erroneous idea but because it didn't go far enough. (Example: Did the expansion of the metal make it bend?) To show the child that he is on the right track, we answer the question by saying that expansion had something to do with it. This lets him know that he is in the right area but needs to ask more specific questions to determine the exact relationship. As pointed out in the previous section, however, we try to discourage such broad general questioning in favor of more concrete tests of hypotheses. One has far greater power and autonomy in propositional thinking if he can test his own propositions deductively rather than asking some authority to decide if they are valid.

(c) Guiding the development of inquiry skills and strategies. The use of the critique session based on the playback of the preceding inquiry session has already been referred to. At this time the teacher takes a more directive role than in the inquiry session itself. His purpose is to make the children aware of the dimensions of process so that they can analyze their own and each others questioning. To some extent the children discover how different forms and strategies or questioning affect the productivity of inquiry, but this process of learning can be accelerated by the teacher. There is a positive side to the critiques. The children should have a chance to see what patterns worked well, and why. Here again, the teacher may need to point out the relationship between process and product. As the children begin to conceptualize the main dimensions of process they can take over some of the teacher's role as critic. They will begin to see the strengths and weaknesses in their own and each other's inquiry.

Not all guidance in inquiry is relegated to the critique session. There are times when, in the teacher's judgment, on-the-spot comments and suggestions can be more effective, and lend greater emphasis to the teacher's point. But excessive guidance during the inquiry sessions distracts the children from the problem episode. Furthermore, the child's preoccupation with content during inquiry makes him less able to think objectively about process.

The management of the inquiry session. The procedures for the management of Inquiry Training in the classroom setting have evolved through several years of trial and error. They do not necessarily represent the ideal, nor have all the teachers trained by us adopted precisely the same procedures. They are described here simply to give the reader a clearer picture of how Inquiry Training was carried out during the experimental training program. As a result of the experimental program some changes are being made in the management of the training. These will be discussed in a later chapter.

(a) *Grouping*. The average class of thirty children is a bit ununwieldy for Inquiry Training. Large groups inhibit some children from participating freely, and in a heterogenous class of thirty there may be enough highly verbal and ideationally productive children to monopolize the question asking. There was evidence in the pilot studies that active participation in inquiry developes the skills more than just the observation of the process. Grouping keeps the number of participants reduced and makes it possible to allow children with similar verbal and intellectual ability to work together. We customarily divide a class into three "platoons." The platoons take turns doing the inquiry for an entire session. The other two platoons keep track of the strategy used by the team "at bat" and also attempt to piece together their own explanations, individually, from the data collected. During the critique sessions the standby platoons assist in evaluating the inquiry of the participating platoon.

(b) *General sequence of events*. Inquiry Training sessions have generally been held once a week for periods ranging from 30 to 60 minutes. Once the children have learned the procedures of operation, the following sequence of events is the most typical.

(1) A problem episode film is shown. (Twice in a row, if the children so request.)

(2) The children commence asking questions for a set amount of time.

(3) The critique may follow immediately or may occur at another time. It should, of course, precede the next inquiry session.

(c) Seating. We have found that the most successful arrangement is to have the question-asking platoon sit in a semicircle around the teacher. The tape recorder is in the center near the teacher, and the blackboard is right behind him. Participation does seem to be affected by the physical distance of the children from the teacher and each other.

(d) Rules of order. For the most part the standard system of hand raising has been the most satisfactory, but we found one modification that helps children follow through with an idea. Once a child has been recognized he has the floor until he gives up. He may keep asking questions and getting answers until he "passes." Very often a single question is not enough to test an hypothesis. When there are five or six hands waving in the air and a child is limited to only one question when he is called on, he might have to wait several minutes before he can ask the second question in his sequence. During this time he may be so concerned with being called on again that he pays little attention to the questions asked by the other children and the answers that are given. If he does get involved with these he might forget all about his own projected series of probes. But by having a chance to follow through with an idea without interruption or pressure, he obtains a greater degree of coordination in his questioning, and is in a better frame of mind to store and process the data obtained by his own questions and those of his platoon-mates.

(e) Recording the data. We found in our early pilot studies that the children cannot store in their minds all the data they collect. Data that become inaccessible after they are collected have little value for discovery or any kind of thinking. The children quite noticeably profit from a system of recording the information they obtain. We therefore teach them to construct an episode analysis chart on the blackboard on which objects, systems, conditions, and events of the episode are entered in the appropriate place. (See Figure 3). It was also a common practice for members of the standby platoons to keep their own episode analysis charts at their seats.

(f) Conferences. Sometimes the children get to a point where they are unable to ask any questions. These "dry spells" usually result when the children have exhausted their off-the-cuff hypotheses based upon an intuitive interpretation of the problem episode. If they have not yet learned the analytical skills and are unable to assimilate the total episode as it is perceived, they can easily feel they have gone as far as possible. On these occasions we have found it useful to declare a two-minute "conference." The children talk to each other and share their ideas and knowledge. Apparently during these periods many children help each other gain perspective that gives them a new basis for attempted assimilation, and usually produces more questions. But this is not a substitute for analysis. Children who are adept in episode analysis rarely find themselves in the position of not being able to ask questions.

CHAPTER IV

THE PROBLEM-EPISODE FILMS

There is nothing new about the use of motion pictures for teaching. But the vast majority of educational films have been almost entirely expository in their design and use. They are usually "programmed" to build certain concepts and generalizations. The film, like the teacher and the textbook, has been cast in the directive role of showing, telling, and selling. Films ordinarily aim at promoting closure. They lead to a set of conclusions, "make a point," or explain an event. The learner is automatically cast in a passive role, expected to follow the filmed sequences and learn the facts, generalizations, or attitudes that the films offer.

The chief advantages of films are that they can present data in very graphic form and they can make use of continuous action to do this. But they are not responsive to the individual needs of the learner. There must be an assumption in preparing an expository film that it is going to be reaching a particular audience with a given intelligence level, conceptual level, and interest range. Unless the audience lives up to these assumptions, some of the children are going to be bored by pacing that is too slow for them while others may be left behind. You cannot ask the film to go over something to make it clearer, or to give another example. If a child wants something repeated or wants to see more of something that is shown, or to get more data in some form, or just wants time out to think, he cannot usually satisfy these needs at the time they arise. He is forced to keep in step with the advancing footage.

But films don't have to be limited to expository use. They don't have to tell a complete story or lead the learner all the way to a particular conceptual level. They can be used quite effectively just to pose questions or problems leaving the subsequent learning activities in the hands of the teacher or the children themselves.

The Function of the Problem-Episode Film in Inquiry Training

The film is used simply to present a clear picture of a physical event and to pose a question about its causation. It is over almost at the point where most instructional films begin. It does not teach, nor does it usurp the autonomy of the learner. It prompts activity on the part of the learner and gives some direction to that activity. It marks out an area for investigation and generally motivates the learner to find an explanation. Finally, it presents a limited set of data. But the information given in the film is rarely enough for analysis of the episode, but it usually _is_ enough to puzzle the learner and arouse his curiosity. The inquiry films are designed to disequilibrate the learner by presenting discrepant events that he cannot fully explain and/or could not have predicted. From a motivational viewpoint it is important to note that the events are real and involve universal physical principles. When the child sees an event he knows is real, and he cannot explain it, he is disturbed. The episode is not isolated. It becomes critical in the child's mind, because it is a challenge to his existing conceptualizations of reality. The typical sixth grade child, who has given up his earlier preference for the imaginary, now wants to know reality well enough to predict, control, and explain it. When he finds a discrepant event he wants to straighten things out and this may include

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straightening out his own concepts. He is ready for inquiry and Inquiry Training.

Why Motion Pictures were Used as the Medium for Presenting the Problem Episodes

Inquiry Training can be conducted with the use of "live" demonstrations in place of the filmed episodes. There were several reasons why we elected to use motion pictures.

(1) It was important that thirty or more children see the episode clearly and at the same time. Many of the objects were rather small, and even a few children at a time watching up close would have difficulty seeing some of the critical details. The films, of course, make simultaneous viewing "up close" a possibility.

(2) The films permitted us to focus upon any aspect of the episode we wanted to stress. This made it possible to limit the children's attention to a part of a larger system.

(3) For the purpose of research it was desireable to be able to replicate the identical episodes in each of our experimental and control groups.

(4) Since the film was not primarily a teaching device, it was not important that the children have the experience of seeing the demonstration performed under varying conditions. Some teachers claim that demonstrations that "fail" have great educational value since they lead the children to become concerned with the reasons for the failure and with the necessary conditions for the successful demonstration. Our objectives were different. The film depicts a specific event under specific conditions. We did not want to depend on accidents to bring to

light the relevant variables in the situation. The purpose of Inquiry Training is to teach children how to discover these variables deliverately and systematically through analysis and experimentation. "Live" demonstrations could not be depended upon to show precisely what we wanted the children to see.

(5) Some teachers have difficulty with laboratory apparatus, even when they have a fairly strong grasp of physics. We felt that elementary teachers would tend to be more competent to operate a motion picture projector than to perform the demonstrations.

(6) After some experimentation we found that the films were not noticeably less motivating than "live" demonstrations. This was particularly true when we switched from black-and-white to color. The switch made a considerable difference in the attitudes of the children, even with films in which the color cues were not at all important to the problem. Our conclusion was that color added an additional dimension of reality and it was the realism that increased motivation.

The Selection of Problem Episodes

The selection and filming of the problem episodes were guided by the following criteria:

(1) The problem had to be immediately intelligible to sixth grade children and inherent in the pictured event without additional structuring. We wanted the films to be disequilibrating, at least to the extent that the children could not explain the events when asked to do so.

(2) The episodes were kept short (not more than two minutes), involving relatively few significant variables. We wanted to make it possible for the children to achieve at least some degree of closure through their

inquiry, although complete closure was never an objective from our point of view.

(3) The materials used in the episode were familiar enough to elementary school children to be real to them. We felt that we could achieve the desired motivational effects by creating episodes in which familiar materials would behave in unfamiliar ways. This would prevent easy assimilation of total events and force the children to analyze and obtain additional data through inquiry.

Each episode was tested twice, once as a "live" demonstration and once in the filmed version. We had the children work on the episode as an inquiry problem and then questioned them about perception of the problem and various details of the film. Sixth-grade children were used exclusively for this pretesting operation and problems that appeared either too elementary or too advanced for this age group were discarded. We found in the pilot studies that problems have to fall within a middle range of complexity for a given age group to be suitable for inquiry. When all the principal concepts relevant to the explanation of an episode were already well established in a child's cognitive structure, the problem is simply one of assimilation. Inquiry is hardly needed in such instances and such problems do not lend themselves to Inquiry Training.

On the other hand, episodes that can be explained only in terms of concepts that are totally foreigh to a child do not offer him a starting foothold. After a certain amount of unsuccessful inquiry even the most tenacious child will become discouraged. Therefore, there must be a certain degree of matching between the age-group and the episodes. There is certainly room for latitude, and starting with the second grade almost any child can make some penetration into almost any episode. But our objective was to produce problem episode films that would maximize the "discoverability" of the underlying concepts.

The Conceptual Sequence of the Film Series

One way of describing Inquiry Training is to say that it teaches children how to relate episodic experiences to conceptual systems. In the process of inquiry not only are the episodes made more meaningful to the child, but his conceptual systems are expanded and coordinated as well. In those content areas where concepts are expanded through inquiry further inquiry becomes even more productive. The result is a spiral effect; inquiry builds concepts and conceptual growth increases the power of inquiry. To capitalize on this effect we limited our training films to a rather narrow segment of physics and arranged the episodes in a sequence that would involve the same concepts in a number of different films. In general the earlier films involve fewer variables related to each other in less complex ways than the later films.

The Relational Constructs Chart for the film series (See Appendix A) lists each of the thirty-three films in the order in which they are used in the Inquiry Training. The titles were informally given for descriptive purposes and do not appear on the films. We have identified 26 relational constructs that can be used in explaining the problem episodes. Sixteen of these apply to more than one film and the sequence is so arranged that films involving the same constructs are grouped together. This grouping is in our opinion an important factor in the process of conceptual growth. By juxtaposing episodes that are perceived as dissimilar but involve the same physical principles, we can increase the likelihood of the children's recognition of these principles.

Test Films

Two of the films were set aside for testing purposes and were not used in the training sessions. They were selected on the basis of difficulty, i.e., the number of constructs needed for explanation, and the complexity of the relationships among the variables. How these test films were used will be discussed in the next chapter. For the purposes of testing, films are far superior to "live" demonstrations because they pose the problem episode in precisely the same form for each child.

In short, films can capture much of the reality of "live" demonstrations yet have the advantage of being standard stimuli. Since the assessment of inquiry skills is based on an analysis of how a child inquires into a standard but realistic episode we believe that in motion pictures we have a useful tool for the study of cognitive processes.

Film Resumes

To conduct Inquiry Training, and particularly to answer the children's questions during the inquiry session, a teacher must have a considerable amount of information about the parameters of the episode, the necessary conditions for the outcome, and a thorough knowledge of the relational constructs needed to explain the events in the film. We could not assume that the average elementary school teacher would have this knowledge and, as a matter of fact, we encountered many who were "science specialists" who did not have a sufficient informational background to use most of our films for inquiry purposes.

Film resumes (See Appendix B) were prepared to help extend the teacher's own understanding of each of the problem episodes. Each resume contained the following:

(a) The film number and descriptive title.

(b) A set of annotated illustrations depicting the objects and events of the episode.

(c) An episode analysis chart of the principal objects and systems and the relevant variables.

(d) A description of the necessary conditions for the outcome of the episode.

(e) A list of the major relational constructs needed to explain the episode.

The resume was in no way a teaching guide in the sense of outlining a series of objectives or a sequence of learnings. The children were never shown the resumes and if they were unable to perform the episode analysis, identify the necessary conditions, or discover the relational constructs as outlined in the resume, no special effort was made by the teacher to give them any of this information directly.

CHAPTER V

THE ASSESSMENT OF INQUIRY

Having some objective means of determining the effects of inquiry training was of utmost importance to the project. One of our major undertakings, therefore, had to be the development of instruments to assess inquiry skills. At the outset there were no such tests in existance, nor were there any operationally defined dimensions of inquiry that could serve as the basis for an inquiry test. We had to identify these dimensions ourselves and design a test to measure them.

The Observability of Inquiry

In order to analyze and assess a process, one has to observe it in motion. It was necessary to make inquiry as "visible" as possible in order to provide samples of behavior that could be recorded, studied and evaluated. Inquiry embraces several types of activity (searching, data processing, discovery and verification) that are not equally "visible" to the observer or accessible for direct measurement. Discovery is largely an internal act. It can be inferred from behavior when a child speaks in terms of principles he has discovered or makes predictions or controls events on the basis of some induced rule. But the cognitive act of discovery itself cannot be directly observed. The only way to determine whether it has occurred is to measure changes in the conceptual structure before and after it has taken place. If conceptual growth has taken place between the two measurements and no other activity but inquiry has interceded, we can assume that some discovery has resulted during the inquiry but not necessarily because of it. Insight is often the result of just thinking about a problem.

Data processing is also largely covert, but can be more easily inferred from observed acts. When the search for data suggests the isolation of variables, the use of controls, the bringing together of comparable sets of data to accentuate similarities and contrasts, we can assume that a systematic plan of data processing is influencing data collection. Of course there are times when children verbally, or in written form, overtly organize their collected data, or process them in some other open and directly observable way. But these occasions are infrequent.

The acts of inquiry that are most commonly overt are those of searching and verifying because in order to perform them the inquirer must obtain new data. And when he is limited to question-asking as the principal means of obtaining new data, these aspects of inquiry become very visible indeed.

The Problem of What to Measure

It seemed necessary to approach the problem of assessment from two directions. While principally concerned with the inquiry process itself and the effects of training on selected process variables, we believed that it would also be worth trying to measure the productivity of inquiry in terms of informational yield and conceptual growth.

There were problems inherent in both approaches. In the assessment of process we would have to rely entirely upon the "visible" dimensions: searching and verification. From these we might infer patterns of data-processing and induction, although there would be no way to verify these inferences. Fortunately the dimensions of inquiry most amenable to training were also the most directly accessible for testing.

As for the measurement of productivity, we had to contend with a number of contaminating factors. Intelligence and science aptitude certainly affect the quantity and quality of learning through inquiry, but at least these can be measured and somewhat controlled. But children also differ in their levels of conceptualization in science and in the richness of their store of concrete experiences. These are probably important factors in inquiry productivity and discovery; and they are much more difficult to measure and control. In short, in measuring conceptual and informational gain over a single period of inquiry, we could not be sure what was contributing what proportion of the gain.

Despite these formidable obstacles we devised a test of inquiry productivity (i.e., information gain through inquiry) hoping that the random assignment of subjects to experimental and control groups in the evaluation study where the tests would be used would serve to equate the groups on all but the experimental variables.

The "Questest"

In order to examine and evaluate the inquiry skills of an individual, we had to first obtain a sample of his efforts to inquire. This had to be done under standardized conditions; there had to be a standard problem, a standard means for collecting data, and standard limits in time and the amount of help that the examiner could provide to the inquirer. Special test films were used to present problem episodes. The children who were tested individually, asked questions which the examiner answered. The entire 25 minute session was tape recorded and the taped protocols were analyzed in terms of process variables. The subjects were tested before and after the inquiry period to provide a measure of informational and conceptual gain. These tests measured the product variables.

This entire testing operation is known as the "Questest". (See Appendix C) It consists of (a) a problem episode, (b) a period of instruction, (c) a period of inquiry, (d) a set of follow-up paper-and-pencil tests to measure informational and conceptual growth and (e) a coding and scoring system for the analysis of the structure and content of the questions asked. The test is given to one child at a time under carefully controlled conditions. The data obtained from the tape-recorded protocols of the inquiry periods present almost infinite possibilities for analysis. For the purposes of the present study we limited the analysis to the strategies of question design and application in data gathering.

(a) The problem episodes. Two films were designated for testing purposes and adapted for the "Questest": Test Film I - "The Cartesian Diver" and Test Film II - "Boiling Water by Cooling." (See Appendix B). They were selected because of their complexity and the large number of relational constructs needed to explain them, and because they consisted of events relatively unfamiliar to sixth-grade children. Children already have partially formed explanations for familiar events. Depending upon their validity, such conceptualizations can help or hinder a child in the inquiry process. But in either case, familiar episodes are more likely to elicit inquiry that is strongly influenced by preconceived formulations. Since we could not measure a child's prior knowledge of the causal relationships in a particular episode without calling his attention to significant variables and in other ways assisting him, we decided to minimize familiarity by selecting very uncommon problem episodes for use in the "Questest."

The film is shown two times. The first time is at the very beginning of a brief instruction period in which the testing procedures are explained. It is shown once again at the end of this period immediately before the child begins his question-asking. The aspect of the episode that is to be explained by the child is identified by a "Why" question that appears on the screen at the beginning of the film (e.g., "Why does the little bottle go down and then come up again?") Before the child is allowed to begin inquiring, the examiner ascertains whether the child clearly understands just what it is he is supposed to explain.

(b) The period of instruction. Just prior to the period of inquiry is a five-minute instruction period in which the procedures of the test are outlined to the subject. At this time two of the most useful types of questions are described and illustrated for him: (1) the verification question and (2) the experiment question. The examiner makes sure that the subject is able to ask at least one question of each type before the period of inquiry is begun. No attempt is made to tell the subject what kinds of questions are regarded as superior.

(c) The period of inquiry. This is the twenty-five minute period in which the child asks questions to gather the data he needs to discover causal relationships in the problem episode. It is our means of determining how a child searches for and obtains information and how productive he is in doing this. Certain limits are placed on the form of questioning to give the subject maximum opportunity to function autonomously in directing the intake of data. Our overall objectives in structuring the inquiry period are: (a) to make data available to the subjects on demand; to create a truly responsive environment, (b) to prevent the subject from depending on the examiner to give him ideas or to point him in any given direction, and (c) to avoid introducing any confusion that was not a function of the child's own thinking or questioning. The chief limitation is the restriction of the subject to use of questions that can be answered by "yes" or "no." The only purpose of this limit is to guarantee that the amount and nature of the information received by the subject from each of his questions is determined entirely by him. Theoretically, there is no way in which an examiner can give more information than is demanded, if he limits himself to an unqualified "yes" or "no." In actual practice, however, qualified answers are given at times to avoid excessive confusion. But no question is ever answered unless it is formulated as to be answerable by a simple negative or affirmative response.

Practically all the limitations placed upon the question answering are there to prevent what we call "brain picking." It is entirely possible to ask a series of questions that can be answered by "yes" or "no" which are not strictly designed for data gathering, but seek instead to tap the examiner's understanding of the relationships involved in the episode. (e.g., "Does pressure have anything to do with the bottle going down or up?") Originally the procedure was to ask the child, "How could you experiment to find that out?" This dumps the problem right back in the child's lap. Unfortunately this had a very depressing effect on the children. It generally pushed them into a different line of questioning. Since we didn't want our procedures to interfere with the children's processes of thought or to frustrate them excessively, we decided to answer such "brain pickers." We recognized that this would help some children obtain more information through poorer, more diffuse and dependent questioning, but it would also bring to light process differences between the protocols with respect to precision and dependency.

The "anything-to-do-with" type of question doesn't provide very good mileage toward discovery. It can save a little time in the elimination of irrelevant variables, but only if they are totally irrelevant. The use of the word "anything" gives the examiner great lattitude for the "yes" answer and as a result the subject is often no nearer his goal than he was before he asked the question.

Sometimes the "brain pickers" are more directed: "Did pressure make the bottle go down?" (See "Cartesian Diver," Appendix B) The question assumes that the causal link is a simple and direct one. Actually, pressure was only one of the relevant variables, and its relationship to the bottle going down is somewhat indirect. Therefore a "yes" answer is incorrect as the question stands. But a "no" suggests that pressure was not relevant, and this is misleading. Such questions are routinely answered: "Pressure had something to do with the bottle going down." In a sense, such an answer does give more information than is asked for, but the information is vague and the answer does not mislead the inquirer.

When questions are asked that cannot be answered one way or the other unless additional information is given, the standard response is, "It all depends," or "I can't answer that without more information." An example of such a question would be (regarding the Cartesian Diver): "Would the same thing have happened if there had been a hole in the side of the little bottle?" The question cannot be answered unless the child specifies exactly where in the side of the bottle. Below the water level it would make no difference at all but above the water level it would. The question is not precise enough and the answer is therefore equivocal.

Questions that simply do not communicate obviously cannot be answered. The examiner tries to get the subject to rephrase his uncommunicative questions, but he does not formulate questions for him. He must also avoid reading into a question more than is actually there.

There is no specific reinforcement of any kind throughout the period of inquiry. The child is not told that a particular question is a good one or that he is getting close to the solution. The examiner may give general encouragement by telling the subject that he is doing well. This is done routinely for all subjects.

(d) The measurement of productivity. One way to evaluate inquiry is to measure how much information it yields and what relationships and principles are induced from this information. This is the "end product" approach which is founded on the assumption that if all other factors are equal, the child who is a better inquirer will obtain more data, and learn more from the data he obtains. We designed a set of three product tests for each test film to sample productivity at three levels of induction. (See Appendix C).

Test A - Measures the subject's grasp of the physical principles involved in the problem episode.

Test B - Measures the subject's recognition of the necessary conditions for the events of the problem episode.

Test C - Measures the subject's knowledge of the parameters of the problem episode (the objects, conditions, and events in the film).

The scores obtained on these tests are known as the product scores. They do not reflect in any way how the subject acquired his level of knowledge or understanding but only where he stands at the end of the period of inquiry. The principles test (Test A) is given twice; once just before the period of inquiry and once just afterwards. This has to be done to control for differences among the subjects in their prior knowledge of the principles. Tests B and C do not have to be given twice since the problem episodes were selected on the basis of their unfamiliarity to sixth graders and presumably nearly all sixth graders are equally unacquainted with the necessary conditions and parameters of the specific problem episodes used in the test films. Because of the marked differences in their content and objectives, the three product tests will be discussed separately.

Product Test A: The problem episodes of the test films involve a number of physical principles or generalizations about the properties of matter. Inquiry, if it is carried far enough, can lead to the discovery of these principles, and the explanation of the episodes in terms of the principles. Product Test A is designed to detect the subject's grasp of these principles by testing his ability to make predictions from a set of data. The data are quite unlike those of the problem episode, but the principles are the same. The child who makes a greater number of correct predictions presumably has a better grasp of the principles in question. Of course, one can predict events purely on the basis of experience without the conceptualization of principles, but such intuitive prediction is limited to situations that are similar to those in which the early experiences were gained. Correct predictions under relatively novel circumstances is more of an indication that a principle or some other abstraction is being used.

The first sample item from Product Test A in Appendix C is based upon a principle involved in Test Film I, Form CD, "The Cartesian Diver," namely the relationship between depth and pressure in a liquid. The child who predicts that balloon B will be smaller than

A or C must be aware that in liquids there is greater pressure at a greater depth, and hence the balloon is smaller there. Now it is true that in order to predict correctly one also has to know that the greater the pressure on the balloon the smaller it becomes, and if a child did not know this principle he could make the wrong prediction despite knowledge of the depth-pressure relationship. Many of the items are somewhat contaminated this way. Actually, this was done deliberately to avoid asking children to make predictions about an abstract variable (pressure) and to substitute a related but concrete and directly observable variable (the size of the balloon). We did this because of the great disparity among children in their concepts of pressure and other such abstractions. We could not assume that when the word pressure is used children all understand it as the same thing.

A key principle in Test Film II, Form BW, "Boiling Water by Cooling" is the relationship between the boiling point of a liquid and the pressure exerted on the surface of the liquid. The second sample item from *Product Test A* measures the child's ability to apply this principle under circumstances that are quite remote from those of the problem episode of Test Film II.

The three containers have water in them subjected to different pressures at the upper surface. Notice again that we present these pressure differences not by using the abstract term "pressure" and giving different readings in lbs. per square inch. Instead we create conditions that we believe convey these differences in pressure more concretely and uniformly to all the subjects. Of course, the correct prediction is that the water will boil first in bucket B because the pressure at the surface is the least. On this particular item, it seemed highly unlikely that a child would be able to get the correct answer on a purely intuitive basis. Children simply don't have the chance to experience the effects of pressure changes on the boiling point of liquids.

Product Test B. The search for causality does not necessarily lead all the way to the discovery of universal principles. Generally speaking, principles are understood more clearly in their abstract form after they have been encountered many times in varying concrete situations. Then, once they have been recognized as necessary relationships they can be used as a basis for explaining concrete instances. But this is a long, slow process and is by no means the automatic consequence of each inquiry session.

More commonly, the immediate result of inquiry is the differentiation of relevant and irrelevant variables and the identification of conditions that were necessary for the problem episode to have taken place. If one can express causality in terms of necessary and sufficient conditions, he is better able to compare the causal relationships of two or more events; and it is only through such comparisons that the discovery of universal principles can occur.

Product Test B was designed to measure the extent to which the subject has identified the necessary conditions of the episode through the process of inquiry. Each item of the instrument proposes one or more specific departures from the conditions of the episode. For example, Item 1 of form BW introduces a modification in the structure of the flask containing the boiling water. A short horizontal spout is added to the neck of the flask. This change is clearly indicated both in the diagram that accompanies the question and in a sentence which states that the spout has been added to the original flask. It is also stated that all other conditions are the same as before. The question posed in each case is: "Will the water boil the second time?" In other words, will this change leave the outcome of the episode unchanged?

It is quite true that subjects who have not actually inquired into the necessity of having an airtight system might still deduce, from an understanding of the principles involved, the effects of adding the tube. But in the long run, the experimental verification of the necessity of a condition is a more certain approach and those who use this approach, all other things being equal, should have a more accurate and complete set of necessary conditions than those who do not.

Product Test C. The first and most critical stage in the process of inquiry is analysis. The objects in the problem episode must be identified, if not by name, at least in terms of their relevant properties. Certain conditions of these objects throughout the episode must be known and events (changes in condition) must also be verified. One cannot begin to search for the necessary conditions for a given event until he has first determined what the actual conditions were. Product Test C was designed to sample the child's knowledge of the parameters (objects, conditions and events) of the filmed episode at the end of the period of inquiry. Some of these data are obtainable simply by watching the film carefully and noting the facts. All of them can have been verified through questioning whether or not they are directly observable. Thus the test is a measure of how much factual knowledge of the parameters of the problem episode the child has at the end of his period of inquiry. Two sub-scores differentiate between the items based on observable parameters and those based on parameters that could only have been determined by inquiry or inference.

An example of an item from Product Test C is Number 3 of Form BW. With the help of a simple diagram this question probes the child's knowledge of what substance occupied the space above the water level in the flask before the flask was heated. There are seven alternative answers to pick from including one that states that none of the other answers is the correct one.

All questions about conditions specify a particular time point or period in the episode because conditions can and do change in the course of the demonstration. One cannot state the temperature of the water in the flask unless he gives this information with reference to a time period. The temperature is much higher at the beginning when the flask is being heated than it is at the end when water is being poured over the flask.

The product tests sample the subjects' knowledge of principles, necessary conditions, and parameters that are relevant to the problem episode used in the "Questest." They are only indirect measures of inquiry skill. Obviously, many variables other than inquiry skill can affect the scores on these tests. Prior knowledge of the principles or previous exposure to the demonstrations, intelligence, the range of the subject's conceptual systems relevant to the episode, and many other variables probably contribute as much to the variance of the product test scores as do the inquiry skills themselves. Since it is virtually impossible to control all these extraneous factors, we designed and used the product tests with the expectation that we would be able to assign subjects randomly to experimental and control groups. While these tests were administered to all the subjects, we were able to achieve random assignment in only 2 of 12 schools used in the study.

(e) The analysis of process. The process of inquiry can be analyzed in terms of the structure and function of the questions asked, the fluency of questioning, the relative frequency of various question types, and the overall plan or strategy used in the grouping or sequencing of the questions. These and other related dimensions constitute the process variables. They provide a picture of a child's patterns of inquiry apart from the conceptual growth or informational gain that result from the inquiry. These variables provide a much more direct indication of the effects of Inquiry Training because the training is directed toward the modification of process only, not toward the development of all the factors that would be likely to improve the productivity of inquiry. In discussing the major process variables, I will try to show the significance of each and point out the criteria used in classifying the questions.

(1) The operational unit (question-clarification-answer) and the fluency score. In the yes-or-no format of the "Questest," inquiry can best be analyzed on the basis of the unit of interaction that starts with a question and ends with an answer. Between these limits may be much interchange for the purpose of clarification. Of course clarification is not required in many units. A typical unit might be as follows: Question - "Was the water in the flask 212 degrees?" Request for clarification - "When do you mean?"

Clarification - "When it was boiling the second time." Answer - "No."

The total number of units used by a child in the course of a 30-minute Questest session provides the fluency score. No differentiation as to the length, structure, function, or content of the questions is made in the tabulation of total fluency scores. Hence, the fluency score is a measure of the number of independent operations performed by the inquirer. If he chooses to cluster them about some thematic center whether it be an hypothesis or an object in the demonstration, the choice each time is that of the inquirer and no question commits him to follow up with any other questions.

The clarification phase of the unit is necessary because the medium of inquiry on the Questest happens to be question asking and answering. Obviously, there must be an adequate level of communication between the asker and the answerer if the asker is to receive the information he is seeking. Since the answerer is limited to "yes" or "no" with some qualifications where necessary, it is up to the inquirer to so structure his questions as to eliminate equivocation. This means that where there is any chance of ambiguity, the questioner should make the necessary distinctions to preclude it. If one is verifying a condition that changes over time, it is necessary to supply whatever constraints are needed to specify a particular time. If one is asking an experimental question and the result is a function of several variables, one or more of which are not controlled in the phrasing of the question, the answer cannot be specific, and clarification is needed. By requesting the child clarify or more fully structure his questions we permit him eventually to get the information he was seeking. Since this is done within the structure of a single unit, we do not artificially inflate the fluency score by counting as a new unit each attempt at further clarification of a single question.

The full significance of the fluency score is not yet known. We have tended to regard it as an index of autonomy since each question is an act of initiation and not a response. While it is quite true that questions vary in depth, ingenuity, originality and other important dimensions, and that the raw fluency score seems to combine grapes and watermellons, so to speak, with equal weight, it was our feeling that combined with other measures that take qualitative distinctions into account, the fluency score does reflect a child's rate of autonomous decision making and ideational output in the search for data.

(2) The analysis of questions by functional type. Once units are established it is possible to classify them according to various systems. We were most concerned with the kinds of information the children were looking for and the ways they structured their questions. After first differentiating more than 100 variations in question structure we were able to group these into a set of eleven mutually exclusive categories. The hierarchical organization of these is as follows:

> Verification Questions: All questions used to identify the parameters of the problem episode (objects, conditions, events) fall into this broad category. Verification applies only to aspects of the demonstration used in the film. There are two main sub-categories of verification. One is the verification of the names or classes of things as they appear in total form, or the analysis of objects or events into component parts, conditions, properties, or relationships.

Categorical verification: The identification of objects or events in terms of categories into which the perceived whole can be fit. This type has two sub-categories:

Nominal: Classification on basis of what category the object belongs to. (e.g., "Was that blade a knife?")

Normative: Classification on the basis of how closely the object corresponds to the norm of a particular category. (e.g., "Was that an ordinary knife?")

Analytical verification: This category includes questions that are used to analyze objects or events in terms of their component parts, conditions, properties, or relationships. This group has four sub-categories:

Condition-descriptive: Questions used to verify specific quantitative or qualitative conditions. (e.g., "Was the blade hot when it was bent?")

Condition-comparative: Questions used to ascertain the relationship between two conditions. (e.g., "Was the blade longer after it was heated than before?")

Structural-component: Questions used to determine the relationship between the parts of a structural whole. (e.g., "Was the blade half one metal and half another?"

Properties check: Questions used to ascertain the properties of an object. (e.g., "Can a Bunsen burner melt brass?")

Implication questions: This second major category was used to classify questions in search of relationships between variables.

Abstract-conceptual: A conceptualized relationship is asked about in abstract terms. There are two sub-types:

Diffuse: The nature of the relationship is not specified. (e.g., "Does the cork have *anything to do with* the water boiling a second time?")

Directed: The nature of the relationship is specified to some degree, (e.g., "Does the cork keep the pressure higher inside the flask?")

Concrete-inferential: Questions that are asked to obtain concrete data through the experimental manipulation of variables. The child then makes inferences about the relationships from the data.

Elimination: Experiments that *eliminate* an object to determine the effect on the outcome of the demonstration.

(e.g., "If the cork were not used at all, would the water boil the second time?")

Substitution: Experiments that replace one object or condition with another. (e.g., "If you held the flask upright instead of at an angle when you poured the cold water on, would the water inside boil the second time?")

Addition: Experiments that add a new object to determine its effect on the outcome of the demonstration. (e.g., "If you put ink in the water, would it still boil the second time?")

Concrete-conceptual: Direct questions that are asked to determine the necessity of a concrete object or condition for the occurrence of an event. (e.g., "Was it necessary to pour water on the flask to make the water inside boil again?")

The relative frequencies of the question types used by an inquirer can reveal much about his goals and the strategy he is employing. For example, if he tries to assimilate the total episode without previous analysis, he is relying more on subjective interpretations, intuitive understanding and a fairly broad system of conceptual structure. The excessive use of abstract-conceptual questions and a maximum of verification questions would be strong indication that this was the case.

The child who first performs an analysis of the episode to identify the major parameters and then manipulates variables to discover the relationships between them, relies more upon analysis and induction. This is a slower but infinitely safer strategy which starts with the known and moves toward higher levels of abstraction. This approach should employ more questions in the analytical-verification and concrete-inferential categories.

Children who have received Inquiry Training are expected to shift their strategies in the direction of the one just described.

Thus the analysis of question-type frequencies is a means of measuring some of the effects of Inquiry Training on strategy.

(3) Communication and equivocation. Quite separate from the function of a question is its form, the completeness and constraints that are necessary to enable the answerer to provide a clear and unequivocal response. Among the Questest process variables were two measures of question form, communication and equivocation.

Communication (c) was judged as either adequate or not adequate. The examiner would decide after each question whether or not he could understand its meaning well enough to give an answer. If he required a restatement, the communication was scored minus (-) otherwise it was (+).

Equivocation (E) was also based on whether an answer could be given. If it could not be given because the question did not provide enough information to make an unequivocal "yes" or "no" possible, the question was given a minus (-) for E. Otherwise it was rated plus (+).

(4) Other process variables. There are many other promising possibilities for analysis of the inquiry protocols. Beyond the form and structure of questions is the actual content, the kinds of information being sought, the range and depth of content coverage. Then, of course, the organization and sequencing of questions show something about the inquirer's goals and strategies. Much more will be known about inquiry and particularly about the cognitive operations of the individual child when we have developed meaningful ways of interpreting the groupings and orderings of questions. For the present investigation only frequencies were used: total fluency,

the frequency of each of the question types, and the frequencies relating to communication and equivocation. These are the only process variables we can interpret now.

The Measurement of Conceptual Growth

A child's conceptual structures are bound to influence his patterns of inquiry. That is, the number of questions he asks, the types of questions, and the things he chooses to ask about, will each be a function of what he already knows. Furthermore, to some extent what he knows after inquiry will be a function of the way he has inquired. Therefore, it was important to have an instrument that could measure certain physics concepts that are basic to the content of the Inquiry Training films.

An examination of existing science tests yielded very little that could be used. Sixth graders are generally given only minor exposure to physics and the standard achievement tests reflect this lack of emphasis. Besides, these tests did not measure the mastery of those physical concepts or principles fundamental to episodes in the Inquiry Training films.

It was necessary to design our own test of concept mastery, the P.C.E. (Predict-Control-Explain) Test (See Appendix D) which provided us with a means of measuring conceptual growth with respect to the 15 most crucial physics principles involved in the Inquiry Training films.

Reliability Estimates

Table I presents the reliability estimates for the Questest Product Tests and the P.C.E.

TABLE I

Reliability Estimates for the P.C.E. and Questest Product Tests

Test	Test-Retest[1]	KR-20[2]	Highest Correlation with other Variables
P.C.E.	.682	.760	.682 (same as test-retest)
Film I			
Product A	.621	.409	.621 (same as test-retest)
Product B	--	.295	.412 (S.T.E.P.)[5]
Product C (obs)[3]	--	.499	.258 (C.T.M.M. Language)[6]
Product C (non-obs)[4]	--	.627	.359 (Product B)
Product C (total)	--	.621	.365 (Product B)
Film II			
Product A	.386	.220	.386 (same as test-retest)
Product B	--	.408	.427 (S.T.E.P.)[5]
Product C (obs)[3]	--	.264	.472 (Product C non-obs)[4]
Product C (non-obs)[4]	--	.582	.475 (C.T.M.M. total)
Product C (total)	--	.627	.488 (C.T.M.M. total)

1. Retest data were not available from Product Test B and C.
2. Kuder Richardson formula 20, a measure of homogeniety.
3. Sub-score based on knowledge of observable parameters only.
4. Sub-score based on knowledge of non-observable parameters only.
5. Sequential Test of Educational Progress - Science Section.
6. California Test of Mental Maturity.

CHAPTER VI

THE EXPERIMENT

The experimental phase of this project was designed to provide answers to these questions: (a) Does Inquiry Training produce measurable changes in the inquiry process when it is conducted in the ordinary elementary classroom setting? (b) Do the acquisition of information and the growth of science concepts through Inquiry Training compare favorably with learning that is programmed and controlled more directly by the teacher?

The experiment took place during the second year of the project (1960-61). The summer of 1960 was given over to the training of teachers in the Inquiry Training methods. During the following school year the twelve teachers who received this training conducted a twenty-four week period of Inquiry Training with groups of children in their schools. The pre- and post-testing of these children with the instruments described in Chapter V provided the data required for the analysis of the effects of the program.

The Selection and Training of Teachers

The teacher was, of course, a critical link between the materials and procedures we had developed and their effects on children. We attempted to make this link as strong as possible. We did not expect to eliminate the teacher variable, but hoped to minimize the possibility of negating any positive effects of our methods by putting them in the hands of teachers who were able to use them to advantage. It was not our purpose at this time to determine the range of teacher talent and preparation necessary to use Inquiry Training. We selected 12 of the most competent teachers we could find and gave them the most intensive and complete preparation possible commensurate with the time and money available. All were men known to have above-average interest in science education. Several had attended National Science Foundation institutes and all but two had taken college courses in physics. At the time of the experiment five were elementary school principals, three were full-time elementary teachers, three were part-time elementary teachers serving also as science consultants, one was a full-time science consultant to an elementary district, and one was a graduate student in elementary education who had formerly been an elementary teacher. With two exceptions these people had more training in physics than the average sixth-grade teacher. All of the teachers chosen had expressed a strong interest in the project and provided assurance that they would receive the complete support and cooperation of their districts in carrying out the work of the project. The only remuneration provided to them was a $300 stipend for attending the 8-week summer training program for which they also received one unit (four semester hours) of graduate credit. No travel or living expenses were provided. It is unlikely that money was a determining factor in bringing any of the participating teachers into the project.

Wide geographical distribution and variety in community size and composition were obtained. Five Illinois cities were represented: Champaign-Urbana, Springfield, Quincy, Rockford, and Highland Park. All but the last are urban centers with populations greater than 60,000. Highland Park is a suburban residential community in the Chicago area with a population having well above average socioeconomic status.

The schools and teachers participating in the project were as follows:

No.	School Name	Location	Name	Inquiry Teacher Position
01	Kimball School	Antioch, Calif.	Fred Kline	Principal
02	Mickle School	Camden, N.J.	John Palumbo	Principal
03	Marshall School	Detroit, Mich.	Norval Scott	Elementary Science Teacher
04	Sterling School	Ft. Lauderdale, Fla.	Edward Eaton	Principal
05	Lincoln School	Highland Park, Ill.	Fred Wilkin	Elementary Teacher-Science Consultant
06	Ranchwood School	Mansfield, Ohio	John Cunningham	Principal
07	Pine Grove School	Orinda, Calif.	Warren Coffey	Science Consultant
08	Rose City Park School	Portland, Ore.	Robert Sheldon	Elementary Teacher
09	Quincy Jr. High School	Quincy, Ill.	Roland McAnulty	Science Consultant
10	Summerdale School	Rockford, Ill.	Eugene Johnson	Elementary Teacher
11	Du bois School	Springfield, Ill.	Carl Renshaw	Principal
12	Wiley School	Urbana, Ill.	Eugene Irving	Graduate Student (University of Illinois)

Seven communities outside of Illinois were represented. Three were large metropolitan centers: Camden (Philadelphia); Portland, Oregon; and Detroit. The schools used in these cities were in residential areas that ranged from middle to low socioeconomic status. There were two additional urban centers outside of Illinois. One was Mansfield, Ohio, and the other Antioch, California, both industrial centers with less than 100,000 population. The school used in each case was located in a middle-income area. The two additional residential communities were Orinda, California, and Ft. Lauderdale, Florida. The former is part of suburban Berkeley, California, and the latter, suburban Miami, Florida. The S.E.S. level in Orinda ranged from middle to upper, and in Ft. Lauderdale from lower to upper-middle.

There was no rural or small town representation and very little from the lower socioeconomic levels. This bias probably resulted from the standards we set for acceptability of teacher applicants. Most teachers with the qualifications we demanded were employed by districts that could afford the more experienced and competent teachers. These are usually in areas that serve middle to upper income families. We were not particularly concerned by this unequal distribution since it was not the purpose of this study to determine the effects of income level on Inquiry Training. In selecting our teachers we had one overriding criterion: the promise we saw in each candidate as a potential user of our methods and materials.

The training of the teachers was accomplished in an eight-week workshop at the University of Illinois in the summer of 1960. The program, which covered three hours a day, consisted of the following elements: (a) Theories of cognition with particular emphasis on inductive methods of learning, discovery, and inquiry. (b) Review of Newtonian physics as it relates to the events in the problem episodes of the Inquiry Training films. (c) Instruction and practice in conducting Inquiry Training and the "Questest."

The theoretical material was presented through readings, lectures and discussions. Tape recordings and transcripts of inquiry protocols were used for illustrative purposes. In connection with the physics review, the teachers had access to the science laboratory of the Elementary Education Department of the University of Illinois where they could conduct experiments on their own to increase their understandings of some of the problem episodes.

A group of 18 sixth-grade children was brought in each day for one hour to enable the teachers to practice the Inquiry Training methods under close supervision. While one teacher was working with the children, the rest were observing. During the hour that followed these practice sessions everybody participated in a critical discussion of the preceding session. In the course of eight weeks each teacher had a minimum of three hours of supervised practice followed by an additional three hours of critical discussion. In addition, each teacher gave two "Questests" to individual children. Tape recordings of these were monitored by members of the project staff and discussed with the individual teacher. Special training in the procedures for giving the "Questest" was necessary since most of the data were to be gathered by this instrument and its reliability was dependent upon the standardisation of testing procedures.

During the following school year all but one of the twelve teachers was visited at least once by the project director and in several locations more than one visit was made. In each case a training session was observed and additional guidance was given the teacher to help him strengthen his Inquiry Training techniques. These visits also gave the director an opportunity to gain a first-hand impression of the circumstances under which the training was being carried out.

Inevitably, when the twelve teachers completed their summer training program and went their separate ways to conduct Inquiry Training, they developed their own individual styles of responding to the children's questions. While from a training standpoint there is no problem with this, when these same teachers conducted the "Questest" they tended to bring the same style over into their question answering in the test situation. Since these styles varied in the amount of help the teacher was giving the children, the "Questest" results showed wide intergroup differences. As soon as this trend became apparent, we arranged to have the final "Questest" administration at the end of the training period given by members of the project staff in three of the twelve schools involved in the study. In two other schools, the teachers adhered so closely to the prescribed testing procedures that their method was comparable to what was utilized in the schools where we did the testing ourselves. Thus, the results analyzed in this report are based primarily on five of the original twelve groups. This in no way reflects on the quality of the training in the groups excluded from parts of the analysis. It is simply the consequence of technical difficulties arising from irregularities in testing procedures.

The Design of the Experiment

The Treatments - Experimental and Control

The independent variable was the presence or absence of Inquiry

Training for the 24-week period of the study. Each school had one inquiry group and one control group. The inquiry groups were sixth-grade classrooms (fifth-grade in Highland Park) where Inquiry Training was conducted at least once a week by a teacher who had attended our summer workshop. Only in a few cases was this the same classroom teacher the children had regularly all week. Thus, for the most part, Inquiry Training was given in isolation from the other work the children were doing.

The control groups were selected with the purpose of providing maximum comparability with the inquiry groups in intelligence and general academic ability. The means by which comparability was achieved had to be decided by the administrators in each of the schools. While we urged that random assignment of the children to the two groups would be most desirable for the kind of statistical analysis we were using, we realized that in most situations this was not possible. Generally we had entire classrooms assigned to one or the other group. In all cases, a conscientious effort was made to select groups that were not especially disparate in their abilities.

The inquiry groups were given one to two hours of Inquiry Training each week. This included practice sessions in which the children used the inquiry method to search for causal relationships in the problem-episode films. Time was also devoted to critique sessions in which the children listened to tape recordings of their previous inquiry sessions, discussed dimensions of the process of inquiry, and learned elements of effective strategy for searching and data processing.

The control groups were given special training also. They were shown the same films that were used in the Inquiry Training sessions. But instead of inquiring into the causality of the problem-episodes, they were taught the relevant physical principles through the usual expository and didactic methods typically employed in science education. This included additional demonstrations, reading assignments, lecture-type expositions, and concrete "laboratory" experiences.

In some cases the same teacher who did the Inquiry Training also taught the control group. In other cases a different teacher was used. We had no control over this factor since the administrative problems at each school were different.

Science "coverage" was not controlled, but in all likelihood the range of relevant topics dealt with by the control groups was equal to, if not greater than the coverage of the inquiry groups. The teachers were able to see to it that the important concepts and principles relevant to each problem episode were discussed and that the outcome of each film was explained in terms of these concepts and principles. In the inquiry groups, the only concepts and principles that could be touched upon were brought out by the children's questions. Even then, no explaining by the teacher was done at all. If the children obtained new understandings it was the result of their own inferences drawn from the data they gathered.

Care was taken not to let the children in either group know that any special importance was attached to one group or the other. Both knew that they were involved in "something special" and in that sense the Hawthorne effect was probably involved in the children's performance, but there was no reason to believe that it was having different effects on the two groups.

A training period of 24 weeks was prescribed for all groups. The sequence in which the films were presented was also fixed. (The basis for this sequence was described in Chapter IV.) But since different groups move along at different rates of speed we did not limit the number of films to be covered in the training period. With two of the thirty-three problem-episode films set aside for testing purposes, thirty-one films were available for training sessions. Sometimes two films were used in one week and on occasion a group would carry over its investigation of an episode to a second week. Therefore, there were differences among groups as to how many of the films were used. Since our measure of conceptual growth (the P.C.E.) was based on concepts involved in the first 21 films in the sequence, and since all groups used in the analysis got at least that far, the differences in coverage among the groups is not likely to have affected the performance of the individual children on the P.C.E.

The Control Variables.

The effects of the community, school, and grade level were controlled by selecting the inquiry and control groups from the same school building. We were unable to control teacher effects either by matching or by statistical means. This, of course, is an important weakness in the design, but it was unavoidable. The teacher effect is a complex phenomenon that is extremely difficult to assess. The personality and behavior of the teacher is probably more important than the method he uses. We could only make the assumption that positive and negative teacher qualities were so distributed over the inquiry and control groups as to weigh about equally on both sides and not to bias the results.

The California Test of Mental Maturity (1957 S-Form for Elementary Grades 4-8) was used to measure intelligence and the scores used as a control variable in the covariance analysis of the P.C.E.

The science section of the Sequential Tests of Educational Progress was given to each subject at the beginning of the study. The original purpose was to provide a control variable for science knowledge and aptitude. But the P.C.E. served this purpose so well that we did not use the S.T.E.P. in the analysis.

Table II provides reference data on each of the six groups included in the analysis.

The Dependent Variables.

The results are contained in three sets of data:

(1) The P.C.E., given the first time prior to the training period and once again at the end, provided a measure of conceptual growth in the areas of physics covered by the first 21 Inquiry Training films. The comparative gains of the inquiry vs. control groups provide an indication of the relative effectiveness, over a 24-week period, of the two approaches to concept development.

(2) The "Questest" Product Tests show the informational yield of inquiry under highly standardized conditions of individual inquiry. This is a measure of how much a child is able to find out about the principles (Test A) the necessary conditions (Test B) and the parameters (Test C) of the problem episode of the test film. These tests are based on the assumption that better inquirers are able to obtain more information and understanding about an episode in 25 minutes of question-asking than poor inquirers.

(3) The "Questest" Process Analysis yields frequencies of question usage that indicate the types of operations the children perform in searching for causal relationships in physical events. The

TABLE II

Reference Measures for the Six Schools Included in the Analysis[1]

School	Group	n	no. of boys	no. of girls	STEP[2]		CTMM[3]		Pre-PCE[1]		Post-PCE[1]	
					$\overline{X}$	S_x	$\overline{X}$	S_x	$\overline{X}$	S_x	$\overline{X}$	S_x
01	Inquiry	14	5	9	45.1	6.0	78.4	15.8	16.9	4.9	22.3	6.9
	Control	14	7	7	39.9	8.4	66.3	21.5	16.8	7.3	21.9	6.5
03	Inquiry	14	9	5	35.2	8.8	63.5	22.3	15.5	3.9	17.9	5.9
	Control	15	6	9	34.2	8.9	45.5	30.6	14.5	3.2	18.1	4.7
05	Inquiry	23	12	11	42.0	7.7	84.0	17.1	18.8	4.7	21.8	7.4
	Control	21	12	9	43.2	5.5	76.5	13.9	15.6	4.4	24.0	5.4
06	Inquiry	24	11	13	41.8	7.2	73.1	20.8	17.7	5.8	24.0	6.0
	Control	22	12	10	38.4	10.4	70.5	26.5	17.4	5.0	21.7	6.3
09	Inquiry	13	9	4	51.2	3.8	97.1	2.8	23.4	3.6	26.9	4.9
	Control	13	7	6	48.3	3.9	92.5	8.6	21.6	4.6	28.0	5.8
12a[4]	Inquiry	13	7	6	40.5	8.3	70.5	25.0	16.6	6.3	21.6	7.8
	Control	13	5	8	41.9	11.7	67.0	26.9	17.9	6.1	21.8	7.1
12b[5]	Inquiry	13	4	9	40.3	12.4	69.9	22.9	18.3	5.9	22.8	6.1
	Control	13	5	8	41.9	9.6	75.2	23.5	20.1	7.3	22.2	8.4
Total	Inquiry	100	48	52	43.2	8.5	78.7	19.4	18.6	5.7	23.6	6.8
	Control	96	48	48	42.0	9.2	74.3	22.3	18.5	5.9	23.6	7.3

1. Six of the schools participating in the study could not be included in the analysis because their data were invalidated for various technical reasons.
2. Raw scores.
3. Precentiles based on age-group norms.
4. Half of Group 12 tested on Film I.
5. Half of Group 12 tested on Film II.

fluency score represents the total number of questions asked. Its meaning and some of its weaknesses are discussed in the previous chapter. Individual frequencies for each of the 12 question categories reflect differences in the goals and strategies guiding the children's inquiry. The differences between the inquiry and control groups with respect to these frequencies provide the best indications presently available of the effects of Inquiry Training on the process of inquiry.

Results

Inquiry Training and Conceptual Growth

Table III presents the mean C.T.M.M. and P.C.E. scores and their standard deviations for the sample composed of the combined data of the five schools (01, 05, 06, 09, and 12) included in the analysis, and the *t* values for the difference between mean pretest and postest scores. Both the inquiry groups and the control groups improved significantly over the 24-week period ($p < .001$). Table IV gives the results of the analysis of covariance of the gains in P.C.E. scores for the inquiry groups and control groups with intelligence (C.T.M.M.) controlled. The difference between inquiry and control subjects on these gain scores was not significant.

Tables V and VI contain analyses similar to those in Tables III and IV except that only the two schools (01 and 12) were used. These were the only schools in the study where complete randomization in the assignment of subjects was used. The gains of both the inquiry and control subjects were significant and as Table VI indicates, the gains in the inquiry groups were greater than in the control groups at a

TABLE III

Comparison of Pre and Post P.C.E. Scores: Schools 01, 05, 06, 09, &12

		C.T.M.M.		Pre-P.C.E.		Post-P.C.E.		Pre-Post	
Group	n	$\bar{X}$	S_x	$\bar{X}$	S_x	$\bar{X}$	S_x	t	df
Inquiry	121	79.93	19.39	18.63	5.66	23.60	6.73	13.23***	120
Control	118	75.59	22.28	18.47	5.95	23.57	7.32	12.35***	117

*** $p < .001$

TABLE IV

Analysis of Covariance of P.C.E. Gain Scores Controlling for C.T.M.M. Scores

Source of Variation	Sum of Squares	d.f.	Mean Square	F	p
Treatments	8.0	1	8.00	.34	n.s.
Error	5,599.1	236	23.73		
Total	5,607.1	237			

TABLE V

Comparison of Pre and Post P.C.E. Scores: Schools 01 & 12

		C.T.M.M.		Pre-P.C.E.		Post-P.C.E.		Pre-Post	
Group	n	$\bar{X}$	S_x	$\bar{X}$	S_x	$\bar{X}$	S_x	t	df
Inquiry	53	73.96	22.32	16.96	6.24	22.77	7.55	7.85***	52
Control	49	70.88	22.43	18.41	6.41	22.00	8.15	4.14***	48

*** $p < .001$

TABLE VI

Analysis of Covariance of P.C.E. Gain Scores Controlling for C.T.M.M. Scores

Source of Variation	Sum of Squares	d.f.	Mean Square	F	p
Treatments	79.7	1	79.70	3.87	$.05 < .10$
Error	2,040.1	99	20.61		
Total	2,119.8	100			

level of significance just short of .05.

To summarize the effects of Inquiry Training on conceptual growth, there is some evidence that learning through inquiry is superior to expository teaching when this growth is measured by the P.C.E. The emphasis on the development of process in Inquiry Training does not apparently detract from (and in two groups it actually enhances) the learning of physical principles.

The Effects of Inquiry Training on the Productivity of Inquiry

The "Questest" obtains a sample of inquiry from each subject under standardized conditions. Special test films are used to pose the problem and the subjects have 25 minutes to ask their questions in a private interview with an examiner. Groups 03, 06, and 12a were given Test Film I, and Groups 01, 05, 09, and 12b were given Test Film II. The product tests of the "Questest" were designed to measure what the subjects had learned as a result of their inquiry. Three dimensions of productivity were measured by Product Tests A, B, and C respectively. The results of each of these tests have been analyzed separately.

Product Test A. This test measures the ability to apply in a new context, principles that are basic to the test film. It was administered twice, once just before the inquiry period and once at the end of it. The expectation was that the scores would either remain unchanged or shift in the upward direction, and that the inquiry groups would show a greater gain than the control groups. Table VII gives the means and standard deviations for the groups given Test Film I. All three inquiry groups showed gains in the predicted direction while two of the three control groups showed no gain and one of these had a small

TABLE VII

Means and S.D.'s on Product Test A (Pre & Post) - Film I

	Inquiry Groups					Control Groups				
		Pre-Test		Post-Test			Pre-Test		Post-Test	
School	n	$\bar{X}$	S_x	$\bar{S}$	S_x	n	$\bar{X}$	S_x	$\bar{X}$	S_x
03	14	3.57	1.28	3.71	1.14	15	3.60	1.45	3.60	1.59
06	24	4.33	2.01	4.42	2.02	22	4.41	1.37	4.27	1.39
12	13	4.23	1.36	4.69	1.80	13	4.08	2.14	4.62	2.14
Total	51	4.10	1.71	4.28	1.79	50	4.08	1.64	4.18	1.69

TABLE VIII

Pre-Post Covariance Analysis of Product Test A - Film I

Source of Variation	Sum of Squares	d.f.	Mean Square	F	p
Treatments (Inquiry vs Control)	.3	1	.3	.16	n.s.
Error	181.0	98	1.85		
Total	181.3	99			

loss. However, none of these shifts was significant. Table VIII summarizes the covariance analysis of the pre-post shifts. With pretest scores controlled, the differences between inquiry and control postest scores were not significant.

Tables IX and X show similar results for those groups that were given Test Film II and the corresponding Product Test A. All of the pre-post shifts were positive and insignificant except in one of the control groups which had a small negative shift. In the covariance analysis summarized in Table X the difference between experimental and control postest scores, with pretest controlled, was not significant.

To summarize the results of Product Test A, there was no clear-cut support for the hypothesis that children receiving Inquiry Training would obtain a greater mastery of the principles in the test film through their questioning and obtain greater gain scores on Product Test A. The differences were generally in the predicted direction but not significant.

Product Test B. This test samples the subject's knowledge of the necessary conditions for the events in the test film to occur. It was given once, just after the inquiry period. It was hypothesized that the inquiry group would obtain higher scores than the control groups. Tables XI and XII give the means, standard deviation and t values. In none of the schools included in the analysis were the differences between the inquiry group and the control group significant. This was true of the totals computed for the groups given Test Film I and Test Film II, respectively.

The ability to discover the necessary conditions of a physical event through inquiry as measured by Product Test B was not improved by Inquiry Training any more than it was by the more traditional teaching methods used in the control groups.

TABLE IX

Means and S.D.'s on Product Test A (Pre & Post) - Film II

	Inquiry Groups					Control Groups				
		Pre-Test		Post-Test			Pre-Test		Post-Test	
School	n	$\overline{X}$	S_x	$\overline{X}$	S_x	n	$\overline{X}$	S_x	$\overline{X}$	S_x
01	14	2.79	1.53	3.43	1.16	14	2.86	1.56	2.71	1.59
05	23	3.04	1.46	3.74	1.39	21	3.05	1.28	3.52	1.60
09	13	2.92	1.26	3.23	.83	13	3.08	1.04	3.23	1.17
12	13	2.23	1.09	2.92	1.26	13	2.46	1.45	3.31	1.38
Total	63	2.84	1.36	3.48	1.16	61	2.88	1.34	3.20	1.47

TABLE X

Pre-Post Covariance Analysis of Product Test A

Source of Variation	Sum of Squares	d.f.	Mean Square	F	p
Treatments (Inquiry vs Control)	2.4	1	2.4	1.63	n.s.
Error	179.9	122	1.48		
Total	182.3	123			

TABLE XI

Comparison of Inquiry and Control Groups on Product Test B - Film I

	Inquiry Groups			Control Groups					
School	n	$\overline{X}$	S_x	n	$\overline{X}$	S_x	t	p	d.f.
06	24	14.38	2.46	22	14.05	2.15	.48	n.s.	44
12	13	14.31	2.50	13	14.62	3.07	-.28	n.s.	24
Total	37	14.35	2.44	35	14.26	2.50	.16	n.s.	68

TABLE XII

Comparison of Inquiry and Control Groups on Product Test B - Film II

	Inquiry Groups			Control Groups					
School	n	$\overline{X}$	S_x	n	$\overline{X}$	S_x	t	p	d.f.
01	14	11.57	2.10	14	11.29	2.27	.34	n.s.	26
05	23	11.91	1.78	21	11.62	1.99	.52	n.s.	42
09	13	12.69	2.32	13	12.85	2.48	-.16	n.s.	24
12	13	11.31	2.25	13	11.23	1.74	.10	n.s.	24
Total	63	11.87	2.08	61	11.72	2.15	.40	n.s.	122

Product Test C. This test samples the child's knowledge of the parameters of the problem episode after the 25-minute inquiry period. It is designed to measure how well a child identifies objects, conditions and events in the course of his questioning. The test items are of two types, "observables" and "non-observables." Subtotals were computed and analyzed for each of these as well as for the total. Table XIII gives the means, standard deviations and t values for the subtotal of "observable" items based on those groups that were given Test Film I. Table XIV provides the same analysis based on the groups that were given Test Film II. None of the differences between the experimental and control groups were significant.

Table XV contains the means, standard deviations, and t values for the subtotal of "non-observable" items based on those groups that were given Test Film I. Table XVI provides the same analysis based on the groups that were given Test Film II. In only one of the six schools represented in this analysis was the difference between the inquiry group and control group significant ($p < .05$).

Table XVII contains the means, standard deviations, and t values for the total Product Test C based on those groups that were given Test Film I. Table XVIII provides the same analysis based on groups that were given Test Film II. In none of the groups or the totals were the differences between the inquiry group and the control group significant.

To summarize the Product Test C analysis, there is no evidence that Inquiry Training has any effect on the child's ability to identify correctly in the 'Questest' any of the parameters called for in Test C.

TABLE XIII

Comparison of Inquiry and Control Groups on Product Test C - Film I
"Observable"

School	Inquiry Groups			Control Groups			t	p	d.f.
	n	$\bar{X}$	S_x	n	$\bar{X}$	S_x			
06	24	3.33	.70	22	3.59	.59	-1.34	n.s.	44
12	13	3.00	1.08	13	3.46	.78	-1.25	n.s.	24
Total	37	3.22	.86	35	3.54	.66	-1.81	n.s.	68

TABLE XIV

Comparison of Inquiry and Control Groups on Product Test C - Film II
"Observable"

School	Inquiry Groups			Control Groups			t	p	d.f.
	n	$\bar{X}$	S_x	n	$\bar{X}$	S_x			
01	14	6.36	1.08	14	6.64	1.22	-.66	n.s.	26
05	23	6.00	1.41	21	5.71	1.42	.67	n.s.	42
09	13	6.85	1.07	13	6.69	1.03	.37	n.s.	24
12	13	6.08	1.44	13	5.39	1.39	1.25	n.s.	24
Total	63	6.27	1.30	61	6.07	1.38	.85	n.s.	122

TABLE XV

Comparison of Inquiry and Control Groups on Product Test C - Film I "Non-Observable" Items

School	Inquiry Groups			Control Groups			t	p	d.f.
	n	$\overline{X}$	S_x	n	$\overline{X}$	S_x			
06	24	8.63	2.92	22	7.00	1.95	2.20	$<.05$	44
12	13	8.00	2.74	13	8.54	3.38	-.45	n.s.	24
Total	37	8.41	2.83	35	7.57	2.64	1.29	n.s.	68

TABLE XVI

Comparison of Inquiry and Control Groups on Product Test C - Film II "Non-Observable" Items

School	Inquiry Groups			Control Groups			t	p	d.f.
	n	$\overline{X}$	S_x	n	$\overline{X}$	S_x			
01	14	25.79	6.31	14	26.07	3.38	-.15	n.s.	26
05	23	24.30	4.04	21	25.62	2.60	-1.27	n.s.	42
09	13	27.23	2.13	13	26.62	3.64	.53	n.s.	24
12	13	22.15	5.54	13	25.31	5.12	-1.51	n.s.	24
Total	63	24.79	4.90	61	25.87	3.59	-1.39	n.s.	122

TABLE XVII

Comparison of Inquiry and Control Groups on Product Test C - Film I
Total Test

School	Inquiry Groups n	Inquiry Groups $\overline{X}$	Inquiry Groups S_x	Control Groups n	Control Groups $\overline{X}$	Control Groups S_x	t	p	d.f.
06	24	12.75	3.29	22	11.46	1.79	1.64	n.s.	44
12	13	11.54	3.62	13	12.77	3.75	-.85	n.s.	24
Total	37	12.32	3.41	35	11.94	2.71	.52	n.s.	68

TABLE XVIII

Comparison of Inquiry and Control Groups on Product Test C - Film II
Total Test

School	Inquiry Groups n	Inquiry Groups $\overline{X}$	Inquiry Groups S_x	Control Groups n	Control Groups $\overline{X}$	Control Groups S_x	t	p	d.f.
01	14	32.43	7.42	14	33.36	4.07	-.41	n.s.	26
05	23	31.04	5.02	21	32.10	3.62	-.79	n.s.	42
09	13	34.85	2.61	13	33.85	4.14	.74	n.s.	24
12	13	28.92	6.18	13	31.39	6.05	-1.03	n.s.	24
Total	63	31.70	5.76	61	32.61	4.43	-.98	n.s.	122

The Effects of Inquiry Training on the Process of Inquiry.

The process data come from the protocols of the inquiry period of the "Questest." Four groups tested with Film II (01, 05, 09, 12) were included in the analysis. The n was 60 in the inquiry group and 57 in the control. Each subject's 25-minute question-asking period was tape recorded and these tapes were analyzed and scored for fluency and question-type frequencies.

Fluency. The mean fluency score for the inquiry group was 50.23 question units with a standard deviation of 19.24. The corresponding mean for the control group was 32.67 question units with a standard deviation of 17.50. The difference between these means is significant at the .0001 level of confidence. Thus, the inquiry group asked over 50% more questions than the control group.

Question-type Frequencies. Frequency of usage was tabulated for each of the question types and comparisons were made between the frequencies obtained for each type in the inquiry group and the control group. Because of the very large mean difference in fluency between the two groups it was necessary to control for fluency in testing for the frequency differences between the two groups. The frequency of every question type was higher in the inquiry group than in the control group partly because the inquiry group was asking more questions in general and this was reflected in every question type in the analysis. Therefore, wherever possible in order to control for the effect of fluency, we performed an analysis of covariance for each question-type frequency with fluency controlled.

One requirement of analysis of covariance is that the regression of the dependent variables on the control be approximately the same for the two groups being compared (homogeniety of regression). Where they are not, analysis of covariance is not appropriate and the adjusted means are not comparable. In our analysis the first F ratio computed for each variable was a test of the homogeniety of regression (F_1). It represents the test of the hypothesis that the slope of the regression line of the inquiry group is equal to the slope of the regression line of the control group. Where this hypothesis is accepted (the critical value was 3.93 with 1 and 113 degrees of freedom) a comparison of the adjusted means (for fluency) is possible (F_2). Where this hypothesis is rejected, that is, when the slopes of the respective regression lines of the two groups are unequal, an F ratio for the differences between the adjusted group means is not meaningful.

Table XIX summarizes the covariance analyses of the question types. Column 1 contains the descriptive names given to each of the question categories. Notice that they are organized in a hierarchical fashion so that some of the categories are simply the summation of several other categories. There is necessarily a relationship between the frequencies of higher order categories and those of the lower order categories that are contained within them.

Columns 2 and 3 contain the mean frequencies of use for each of the question categories in the inquiry and control groups respectively. Columns 4 and 5 contain the corresponding standard deviations. Column 6 contains F_1, the test of homogeniety of regression and column 7 contains F_2, the test of significance between the inquiry and control group adjusted means for those question categories where the regressions were found

TABLE XIX

Summary of Analyses of Covariance of the Frequency of the Usage of Question Categories
($N_I = 60, \; N_c = 57$)[1]

							Regression Slope: Question-type Frequency vs. Fluency	
(1) Question Type	(2) Inquiry $\bar{X}$	(3) Control $\bar{X}$	(4) Inquiry S_x	(5) Control S_x	(6) F_1	(7) F_2	(8) Inquiry	(9) Control
I. Verification	21.83	10.83	12.34	8.10	3.45	2.09		
A. Categorical	1.52	.53	1.97	.93	7.67	n.c.[2]	-.02	.03
1. Nominal	.90	.32	1.58	.71	9.36	n.c.	-.02	.01
2. Normative	.62	.21	.99	.61	.98	.07		
B. Analytical	20.32	10.30	12.28	7.85	5.93	n.c.	.44	.24
1. Condition-Descriptive	15.42	7.88	10.37	6.22	6.63	n.c.	.36	.18
2. Condition-Comparative	1.35	.77	2.21	1.33	.23	.58		
3. Structural-Component	3.07	1.33	2.90	1.78	.06	2.45		
4. Properties Check	.48	.32	.90	.65	8.28	n.c.	.02	.00
II. Implication	27.52	19.93	8.72	10.50	10.60	n.c.	.40	.70
A. Abstract-Conceptual	14.33	10.60	7.99	9.17	11.61	n.c.	.25	.45
1. Diffuse	5.52	5.09	5.02	4.68	.76	5.60[3]		
2. Directed	8.82	5.51	5.70	5.77	7.02	n.c.	.14	.26
B. Concrete-Inferential	13.18	9.33	2.42	1.90	1.22	.03		
1. Experimental-Inferential	11.97	8.70	8.32	7.88	.83	.02		
a. Elimination	2.20	.91	2.57	1.51	2.87	2.18		
b. Substitution	9.50	7.61	6.89	7.22	2.24	.07		
c. Addition	.27	.18	.61	.51	.32	.32		
2. Necessity	1.22	.63	1.75	1.72	2.44	.04		

1. Analysis includes groups 01, 05, 09 and 12.
2. n.c. signifies that the adjusted means are not comparable.
3. $p < .05$.

to be homogeneous. Column 8 contains the slope of the regression lines of the inquiry group for those question types where regression is not homogeneous. Column 9 contains the corresponding slopes for the control groups.

Verification is one of the two main question categories. The mean number of verification questions asked by the inquiry group was more than twice as great as the number asked by the control group (21.83 vs. 10.83). Since F_1 was not significant, it was possible to test for the significance of F_2. With fluency controlled the use of verification questions was equivalent in the two groups.

Verification questions have two main sub-types. The categorical questions and the analytical. F_1 for the categorical questions was significant which meant that the adjusted means could not be compared using analysis of covariance. The frequency with which this category was used was so low (the mean for the inquiry group was 1.52 questions and for the control .53) that covariance would not have been an appropriate test in any event.

Analytical questions accounted for by far the largest portion of the verification category. There were almost twice as many analytical questions asked by the experimental group as by the control (20.32 vs. 10.30). Since F_1 was significant, the adjusted means could not be compared using analysis of covariance. Figure 4 shows the slopes of the regressions (analytical questions vs. fluency) in the inquiry group and the control group. At the high and middle fluency levels the inquiry subjects asked more analytical questions than the control subjects. The reverse was true at the low fluency levels.

By far the most frequently used question type in the analytical group was the condition-descriptive category. Its mean frequency in the inquiry group was nearly twice as great as that in the control group (15.42 vs. 7.88). Since F_1 for this variable was significant the adjusted means could not be compared. Figure 5 shows a pattern similar to that for the entire analytical category in Figure 4. This is obviously because most of the questions that fell into the analytical group were of this sub-type. Thus, at high and middle fluency levels the inquiry subjects asked more condition-descriptive questions than did the control subjects, and at the low levels of fluency the reverse was true.

Two other sub-types of the analytical category, condition-comparative and structural-component had non-significant F_1 and F_2 ratios. This means that with fluency controlled, both groups made equivalent use of these two question sub-types. Since the actual use of these types was very small in both groups (the mean frequencies were 1.37 and .77 in the inquiry group and 3.07 and 1.33 in the control) the difference between the groups on this variable could not be tested adequately by the covariance model.

The fourth sub-type of the analytical category, properties check, received a very small amount of use, an average of less than half a question unit per subject in both groups. F_1 was significant, so no comparison could be made between the adjusted means.

Implication was the second main question category. The mean number of questions in this category was 27.52 in the inquiry group and 19.93 in the control. Since F_1 was significant the adjusted means could not be compared. Figure 6 compares the regressions (implication vs. fluency) in the inquiry and the control groups. At the high and middle fluency

FIGURE 4

Comparison of the Regression of the Number of Analytical Questions on Fluency in the Inquiry and Control Groups

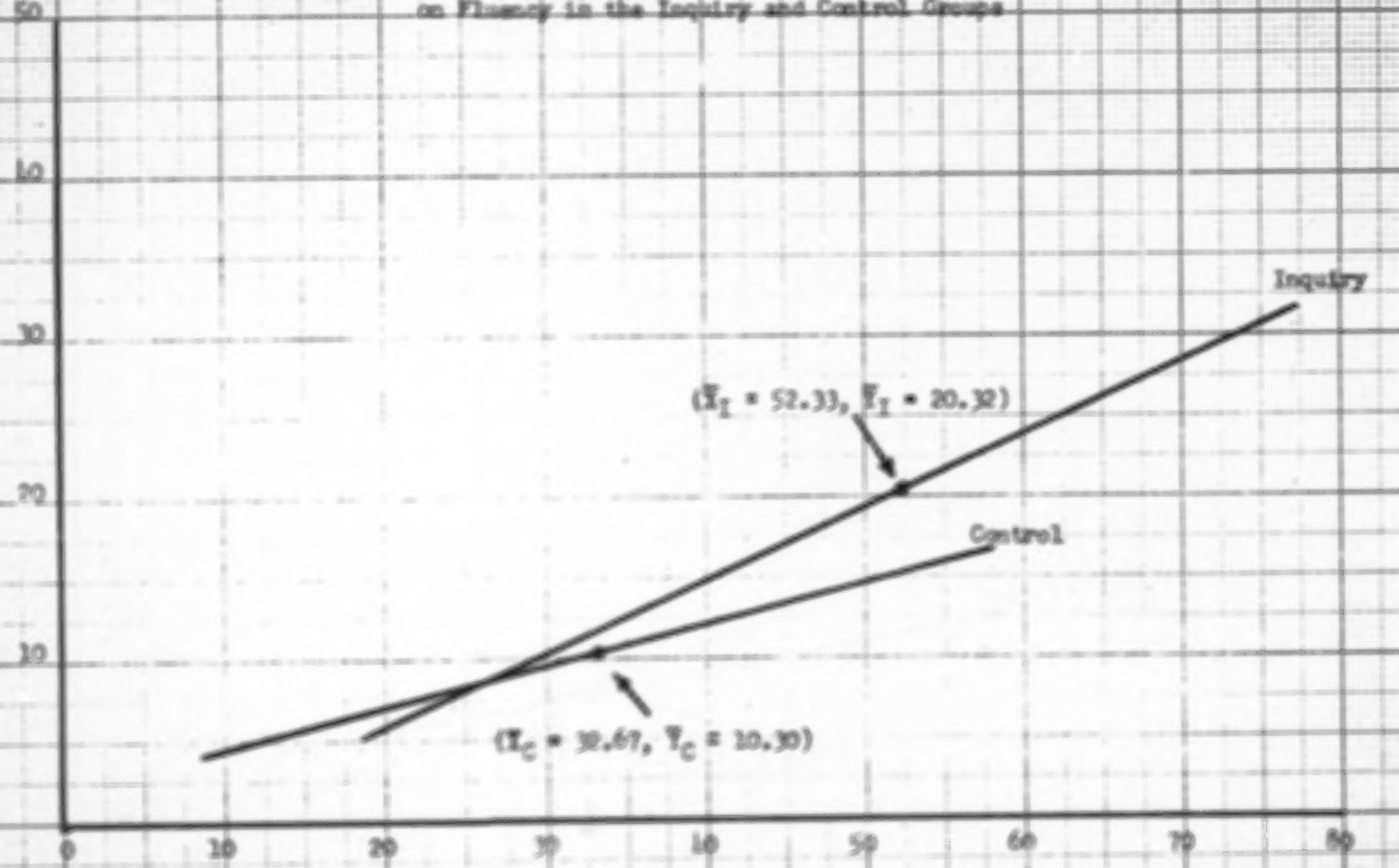

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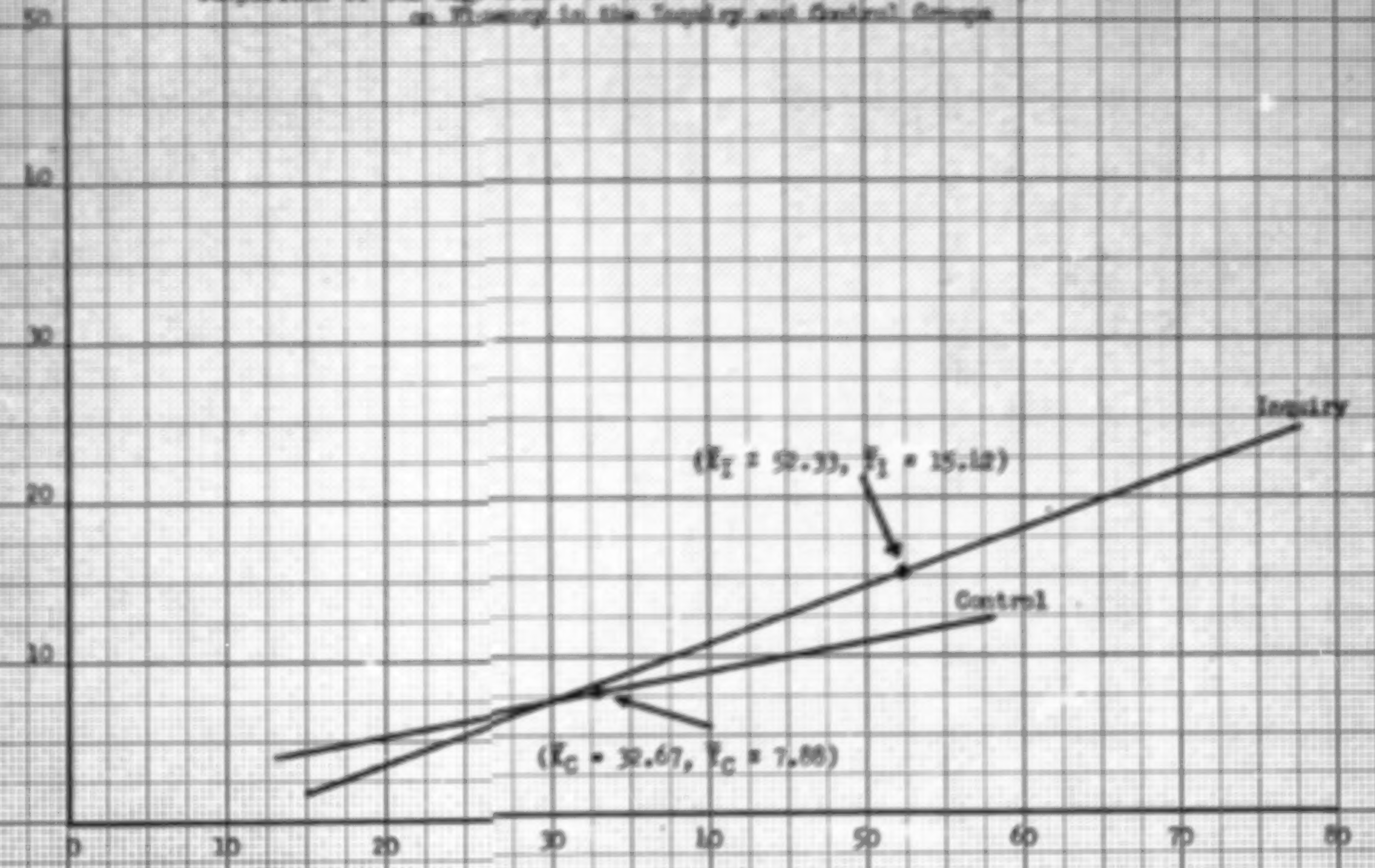
FIGURE 5

Comparison of the Regression of the Number of Condition-Descriptive Questions on Fluency in the Inquiry and Control Groups



levels the control subjects asked more implication questions than did the inquiry subjects. At the lower levels of fluency the reverse was true.

Implication category has two main sub-types, abstract-conceptual and concrete-inferential, each of which accounted for about half of the total of implication questions. The mean number of abstract-conceptual questions was 14.33 in the inquiry group and 10.6 in the control. Since F_1 was significant the adjusted means could not be compared. Figure 7 shows the regressions (abstract-conceptual vs. fluency) in the inquiry and control groups. At the high and middle levels of fluency the control subjects asked more abstract-conceptual questions than did the inquiry group. The reverse was true at the lower levels.

The two varieties of abstract-conceptual questions are the diffuse and the directed. The F_1 for the diffuse type was not significant and the F_2 ratio was significant at the .05 level of confidence. Thus the adjusted mean of the control group was significantly higher than that of the inquiry group in the use of diffuse abstract-conceptual questions.

The F_1 for the directed variety of abstract-conceptual questions was significant, so the adjusted means could not be compared. Figure 8 shows the regressions (directed abstract-conceptual vs. fluency) for the inquiry and control groups. At the high and middle fluency levels the control subjects asked more directed abstract-conceptual questions than did the inquiry subjects. At the low levels of fluency the reverse was true.

The use of the concrete-inferential category of implication questions was roughly as frequent as the use of abstract-conceptual questions. The mean frequency of this type was 13.18 in the inquiry group and 9.33 in the

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FIGURE 6

Comparison of the Regression of the Number of Implication Questions on Fluency in the Inquiry and Control Groups

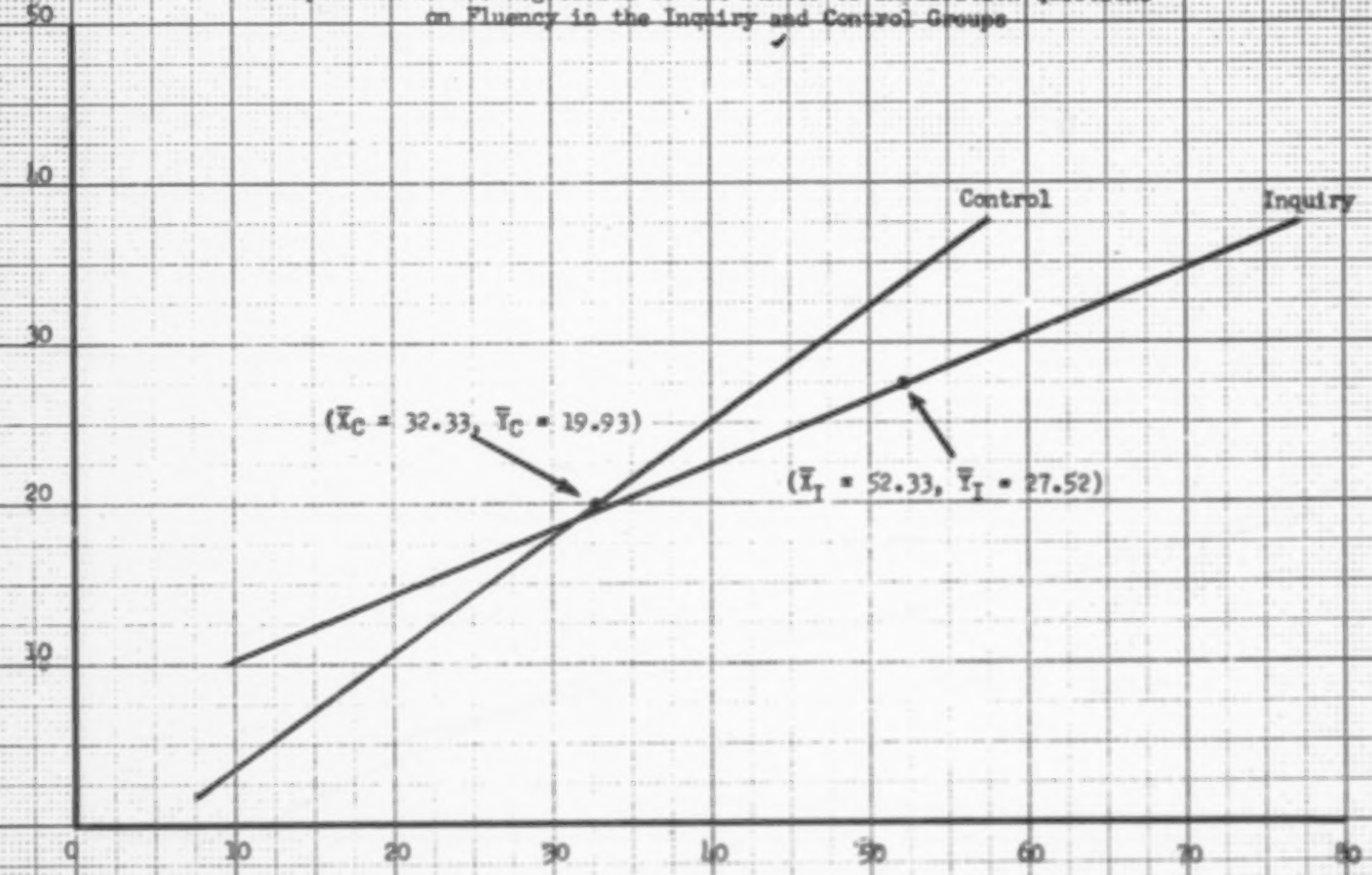

FIGURE 7

Comparison of the Regression of the Number of Abstract-Conceptual Questions on Fluency in the Inquiry and Control Groups

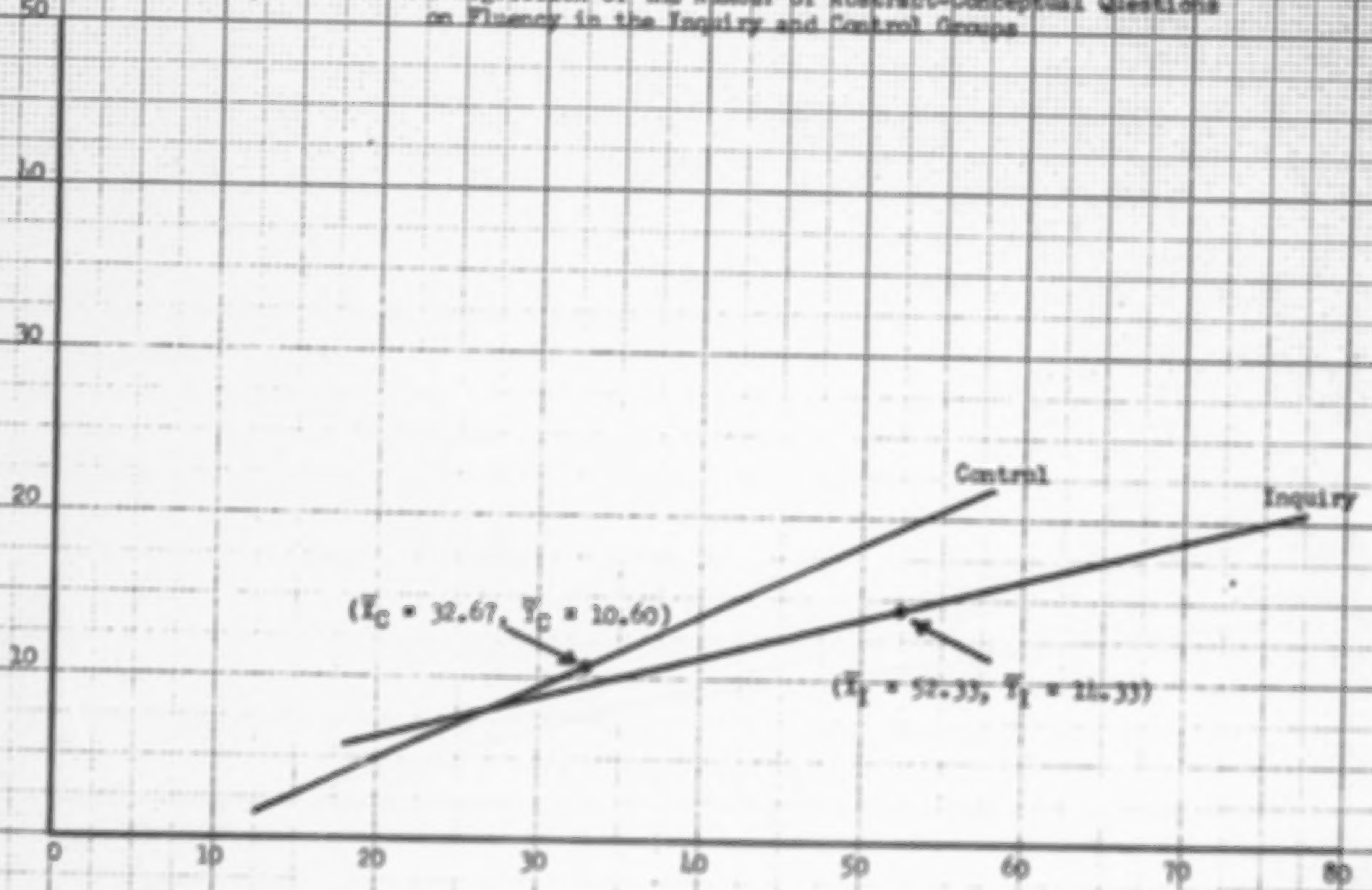

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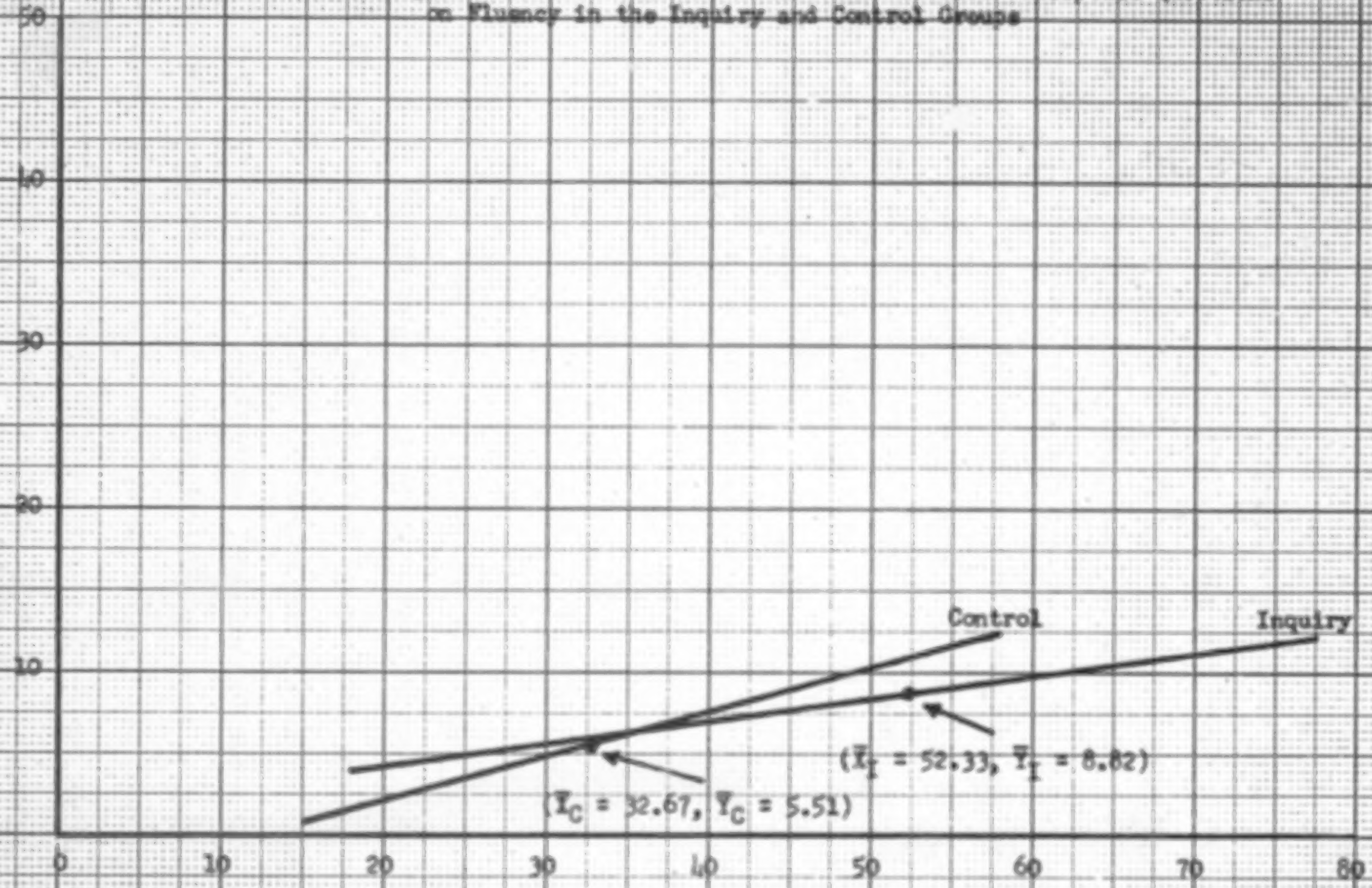
Figure 8

Comparison of the Regression of the Number of Directed Abstract-Conceptual Questions on Fluency in the Inquiry and Control Groups



control. F_1 was not significant nor was F_2. Thus, the adjusted means of the inquiry and control groups on the use of this category were not significantly different.

Of the two sub-types, experimental-inferential and concrete-conceptual, the former accounted for a much larger portion of question units (11.97 vs. 1.22 in the inquiry group and 8.70 vs. .63 in the control). With both sub-types the F_1 ratio was non-significant, as was the F_2. Thus the means of the inquiry and control groups were not significantly different.

The experimental-inferential sub-type was further broken down into three varieties: experiments of elimination, substitution and addition. The bulk of the questions were of the substitution variety, which had a mean of 9.50 in the inquiry group and 7.61 in the control. The adjusted mean difference between the inquiry and control groups was not significant on this variable. In the other two varieties, elimination and addition, the mean values were too low for meaningful comparison by the covariance model.

Discussion

The purpose of this study was to put to a test a specific method of developing the inquiry skills of elementary school children. The first part of the project was the development of the materials and methods to be used in the Inquiry Training. The second part was the preparation of teachers to carry it out in classrooms. The third part was a twenty-four week training period in which Inquiry Training was given to fifth- and sixth-grade children by the teachers we had trained. The final part was the measurement of the effects of this training period and the comparison of the results to those achieved by control groups. This chapter has been devoted to a description of the conditions and procedures of the fourth part of the study and a presentation of the results of the testing and data analysis. In this final section of the chapter the results of the experiment are discussed. These results pertain only to Inquiry Training as it was actually carried out in the schools involved in the analysis. We cannot generalize from them about the adequacy of other similar methods or teaching materials except to the extent that we were able to demonstrate that certain aspects of the inquiry process can be modified in the classroom through Inquiry Training. In all likelihood, variations of the methods we used can produce more pronounced results. The problem episodes that were chosen for the problem-focus films, the amount and type of training given to the teachers, the rules imposed on the children during the inquiry sessions, and the amount of time devoted to Inquiry Training each week all had their individual effects on the final results. Undoubtedly more sensitive tests could have shown changes in the inquiry processes and conceptual structures of the children studied that our instruments did not detect.

These and many other factors need further investigation. From the results of this experiment we cannot arrive at many firm conclusions either in relation to a theory of inquiry or the practical effects of Inquiry Training in a broad or long range sense. We only know some of the short term effects of the very specific method we used. I intend to extrapolate from these findings in the following discussion of the results, but it is to be understood that hypotheses rather than conclusions are being offered.

Limitations of the Study

This was quite frankly applied research, which in itself is a limiting factor if one wishes to draw inferences about cognitive processes from the results. Even as a test of Inquiry Training there were certain limitations to the study.

The first group of limitations had to do with the training procedures themselves. Inquiry Training was introduced into the classrooms as something quite novel. It was accepted as a new experimental technique which was being tried out in a small way for a period of time to see what effects it had. In almost all cases it was introduced in isolation from the existing curriculum. That is, for one or two periods a week the class had "Inquiry Training" and very few attempts were made to relate it to topics or problems currently under study by the group. The chief reason for this was our decision to keep Inquiry Training isolated for purposes of control. If teaching and inquiry were mixed we could not know the extent to which conceptual growth was a function of one or the other. It has been our belief all along, however, that maximum conceptual growth comes from some kind of combination of the two. We therefore believe that keeping inquiry in isolation from the rest of the curriculum was artificial and it imposed a limit on the effectiveness of the inquiry approach to learning.

A second major limitation to the training was the relatively small amount of time devoted to it. One or two hours a week is a very small amount of time to provide experience in autonomous searching activities, especially when the rest of the week is devoted to activities where the pupil has considerably less control over his own learning activities.

Using inquiry every day as part of learning in a wide variety of content areas is likely to have a much greater effect on the children than one period a week in isolation from everything else.

One additional limiting factor had to do with the inquiry teachers. Their special preparation covered an eight week period and they had opportunities to watch a great many training sessions, but each teacher had only two sessions to conduct by himself. More supervised practice would probably have resulted in more skill, particularly in carrying on the very important critique sessions.

There were also limitations in the evaluation aspects of the study. To begin with, the "Questest" inquiry session was individually administered. The examiner answered each question to the best of his knowledge. He tried to standardize his responses according to set procedures. But there is no question that the process of inquiry and the learning that resulted from it was a function of how the examiner happened to respond to a particular set of questions or to a particular child. Examiners inadvertantly communicated important information by their facial expressions and tone of voice. The general behavior of the examiner probably had a strong influence on the motivation of some children. We do not know how much "Questest" variance can be attributed to the interaction between the examiner and the subject, but the fact that this was not controlled must be regarded as a limitation.

Because the "Questest" relies heavily on verbal communication, the child who has low verbal abilities is handicapped. The test has no way of sampling properly the inquiry skills of children who are hampered in formulating questions simply because of language difficulties.

Several unavoidable problems came up in the course of the experiment which posed limitations on the analysis and interpretation of the data. Because not enough time had been devoted to training the teachers in the administration of the "Questest," a large proportion of the data was not usable. In addition there were two schools where such a marked bias had crept into the assignment of subjects to the inquiry and control groups that these groups could not be used.

Some Interpretations of the Results.

Inquiry Training and Conceptual Growth: Both the inquiry and the control groups had equal exposure to the problem-episode films. In the case of the former no attempts were made to teach any concepts of physics. The only instruction given by the teacher was in helping the children develop a strategy of inquiry. In the control groups all the time was devoted to teaching physical principles in relation to the problem episodes. Despite this greater emphasis in the control group on content, in two of the schools the inquiry group showed significantly higher gain scores on the P.C.K. than the control ($p < .06$) for the training period, and in the rest of the schools there were no significant differences between the groups. Apparently Inquiry Training is accompanied by conceptual growth that is equal, if not superior, to that achieved under the traditional expository methods of instruction. This finding is consistent with our theoretical position. Expository teaching, even in the hands of skilled teachers tends to rely on more-or-less programmed experiences and explanations that are essentially teacher-engineered. The influence of the learner on the data-flow is relatively small; he must assimilate the experiences as they come. If he cannot assimilate them, rather than break the continuity of the teaching program (and in the process reveal his lack of comprehension to the teacher and the group) he either learns what the teacher is teaching at a verbal level only without any real assimilation, or he gives up entirely and lets his mind drift away from the subject at hand.

With the inquiry method the autonomy of the learner is paramount. For the learner, influencing the data-flow is the appropriate mode and is strongly encouraged by the teacher. Passivity and dependence on the teacher to shape conceptual structures is simply not a feasible means of learning under these conditions. Conceptual structures are applied to the events of the problem-episodes through the efforts of the children. So long as events are discrepant for the child he can continue to gather data and test new hypotheses in an effort to achieve greater assimilation. There can be no retreat into meaningless verbalism in place of genuine understanding.

Where the expository method is adequate for assimilation, and in many teaching situations it is, the rate of learning is probably much more rapid. The experienced teacher can select just those experiences that are most likely to lead to the desired understanding. The trial-and-error searching that characterizes inquiry is more time consuming. Where the chief consideration is promoting maximum conceptual growth in the minimum amount of time, there probably ought to be some combination of exposition and inquiry. Just how this combination should be made would probably have to depend on such factors as the nature of the subject matter, the age and conceptual development of the children, size and homogeniety of the group, and the teaching materials available.

Inquiry Training and the Process of Inquiry

Conceptual growth is not the only consideration. Our primary concern was building the skills and strategies of inquiry. Inquiry Training is designed to make this process more autonomous, productive, and precise. The "Questest" enabled us to sample the inquiry of our trained and control subjects under somewhat standard conditions and to compare them in terms of how they were inquiring (process variables) and how much they were learning from their inquiry (product variables).

The Effects of Inquiry Training on Fluency: The inquiry group asked more than 50% more questions on the "Questest" than the control group. Just what aspect of the training produced this effect is not known. It could have been wholly a conative phenomenon. By having regular practice in inquiry the subjects may have developed some new self-confidence which reduced inhibition. Perhaps they learned that asking a question was not just a way of getting somebody to explain something, but came to see it as a means of obtaining new data which could be used to analyse, interpret events and increase their understanding of complex phenomena. Bruner (1961) suggests that learning by discovery develops in the child a "sense of intellectual potency" and a "faith in the regularity of the universe." Perhaps the child who comes to possess this sense and this faith by having many opportunities to participate in autonomous searching and discovery becomes more willing to inquire when he gets the chance.

Another possible explanation for the higher fluency in the inquiry group is based more on cognitive considerations. A major part of the training is to help the child come to see a kind of logical structure for explaining events. The teacher helps the children recognise relationships between an observable episode and a set of discrete bits of information that describe the episode in terms of a set of variables. The episode, as observed, is unique, and as a total unanalyzed experience, cannot easily be related to other episodes except in very superficial ways. But when it has been transformed through analysis into sets of conditions that are discrete values within sets of variables, it is possible to compare these values with those that represent other episodes which have likewise been analyzed in terms of the same variables. And eventually, after observing a series of episodes, analyzed in terms of the same variables, one begins to see consistent relationships between the variables.

Not many of the children we worked with came to the point of having such a sophisticated grasp of the function of analysis. But they did analyze episodes and they did use the data obtained to synthesize relational constructs to account for observed relationships between variables. Children who have operated in this way for many weeks may come to have less difficulty thinking up questions to ask. Their goals are clearer. They know more of the kinds of questions they need to ask to get the information they are looking for. It is quite conceivable that this kind of knowledge and experience in inquiry would increase the fluency of question asking.

A third possible explanation of the increase in fluency in the inquiry group is that these subjects had more practice in question-asking within the Inquiry Training format. Since the testing situation was very similar to the training conditions, the children in the inquiry groups, who had built up a repertoire of question-types and patterns in the training sessions could draw upon these during the "Questest." By having many opportunities to watch and practice question-asking they had a better idea as to what kinds of questions could be asked and how valuable they might be in obtaining information.

Whatever the explanation is, and probably more than one factor was responsible for the fluency increase, Inquiry Training produced a greater volume of questions which enabled the inquiry group to obtain more information. From a practical viewpoint this is a very encouraging result since it suggests that there are steps that teachers can take to increase the sheer volume of data intake through searching.

Shifts in the Relative Frequency of Question Types: We made a deliberate attempt to teach children to build structure into their inquiry. From a purely logical viewpoint it is necessary to obtain certain kinds of information in order to make sound inferences. We stressed analysis - the verification of objects, properties, events and conditions - to be used in advance of inferential thinking, hypothesis formation, or generalization. On the "Questest" we expected the use of analytical questions, particularly the condition-descriptive type, to be greater in the inquiry group than in the control. This was borne out by the results, although the difference between the inquiry and control groups on this variable could not be tested by covariance because of the interaction between fluency and the use of analytical questions. But it was obvious that among the children with higher fluency scores the inquiry groups were using far more analytical questions than the control groups and this difference was much greater than could be accounted for by differences in fluency alone. One way of explaining this result is that children varied considerably in the degree to which Inquiry Training increased their fluency scores, and those who did increase these scores tended to do it by asking a great many more analytical verification questions. This is clearly seen in Figure 4 where the slope of the regression of analytical question usage on fluency is much steeper for the inquiry group than the control. The inquiry group not only asked more questions, but a disproportionate share of this increase was in the form of analytical questions, which are the most productive of data.

The use of the two major sub-types of the Implication category, abstract-conceptual and concrete-inferential was affected by Inquiry Training in different ways. Our training procedures were designed to reduce the frequency of abstract-conceptual questions, which are global in structure and non-analytical in function. They are attempts to reach a solution by describing hypothetical relationships which are tested by questions which simply ask if the structure is valid. This is highly dependent inquiry and it was our expectation that Inquiry Training would reduce the usage of this question category. The results largely fulfilled our expectations. The diffuse variety of abstract-conceptual was significantly lower in the inquiry group. The directed variety was also lower in the inquiry group but the means of the inquiry and control groups could not be compared by covarience analysis because of the interaction effect with fluency. But Figure 8 shows how the use of the directed abstract-conceptual question in the control group tended to exceed that in the inquiry group more and more as fluency increased. This means that Inquiry Training tended to depress the relative use of this type of question, although the absolute frequency of this type did increase somewhat with fluency.

The use of the concrete-inferential form of implication question seemed not to be affected at all by Inquiry Training. The control group made about the same proportional use of experiments as did the inquiry group. We had expected to find a difference here since Inquiry Training placed emphasis on the use of experiments to determine the relevance of variables and to test hypotheses.

Perhaps the fairly extensive use of this category by both groups is an indication that the experimental mode of thinking is already a characteristic of the sixth grade child. He has engaged in concrete operational thought since he entered school. He is accustomed to exploring his environment by manipulating it. Experimentation is probably much more primative than analysis in the developmental sequence of inquiry skills. The former starts with a set of concrete conditions and simply requires the changing of one or more of them and the observation of the consequences. The infant performs rudimentary experiments in his crib as he plays with beads and rattles and begins to correlate actions with reactions. Analysis on the other hand requires a system of categories. To ask about temperature, pressure, or volume meaningfully one must first have conceptualized these variables.

In the analysis of question types we did not differentiate the ways in which experimental questions were used, particularly the combinations and sequences of experiments. It is quite possible that this is where the inquiry group differed from the control rather than in the sheer number of experimental questions used. Experiments are more productive when they are combined to determine the relevance of a set of variables or to verify hypotheses. But we did not analyze protocols in terms of question cluster or patterns because it involved too much guesswork, and we have not yet worked out the analysis of the groupings of questions.

Inquiry Training and the Productivity of Inquiry.

Despite the fact that the inquiry group was more fluent in their questioning and made greater use of verification questions, their scores on the "Questest" product tests were not significantly different from those of the control groups. Apparently, the productivity of inquiry, as measured by the product tests, is a function of more than total fluency and the amount of verification that is done. There were indeed substantial differences in product scores among the subjects in both the experimental and control groups. But very little if any of this variance can be attributed to the presence or absence of Inquiry Training. What then are the other factors that may have been so influential that they made the effect of Inquiry Training appear negligible?

It should come as no surprise to the reader that we have observed in all inquiry sessions that a child's store of concepts and information gives him an enormous advantage in the inquiry process. If the building of a conceptual model to accommodate a discrepant event is largely a matter of scanning one's store of conceptual frames to try out ones that look promising, it would seem to be a reasonable assumption that all other things being equal the child with the richest supply of frames will be the most successful in the long run. While children extend their conceptual systems over a prolonged series of investigations in the Inquiry Training program as the P.C.F. data suggest, they do not necessarily add significantly to their concepts during a single inquiry session, particularly when this session is a solo performance.

What a child already knows about an event is probably the most important factor in the determination of his ability to find out more about its causality. This is true even in the process of analysis since one cannot sample a particular variable if he has not yet conceptualized it.

There is at least one other factor that may have contributed to the finding of "no difference" between the experimental and control groups on the product tests, and that would be the inadequacy of the tests themselves to sample what the children had learned as a result of their inquiry. This would probably not pertain to Product Test A since that was given before and after the inquiry session and the important variable was the gain score. But Product Test B was designed to assess the subject's knowledge of the necessary conditions for the outcome of the problem-episode film. A person who had a grasp of the major physical principles in the film would be able to deduce logically the necessary conditions without actually having ascertained these conditions through inquiry. Therefore Inquiry Training may well have had no effect on the Product Test B scores of many of the subjects.

The Product Test C scores are based on the child's knowledge of the parameters of the problem episode in the test film. This test would seem to reflect the productivity of inquiry at least where episode analysis is concerned, but actually it was possible to include only a very small sample of the objects, conditions and events of the films in the test. If a child had happened to verify those parameters asked about in the test, his score would be high. On the other hand, he might have asked many questions about parameters that were not covered in the test causing him to receive a low score despite a highly analytical and fluent style of inquiry.

At best, the product tests are round-about measures of inquiry skill which appear to be contaminated by other factors. The extent to which the variance of the test scores is a function of inquiry skill is an important but as yet unanswered question.

Conclusions and Recommendations

If one can conclude anything from this study it is that even a very small amount of experience and training in inquiry under less than ideal conditions can produce measureable improvements in the question-asking of sixth-grade children. But the significant results of such training can only be seen in the transfer of this learning to a broad range of activities. If Inquiry Training is given as a "one-shot" program in the sixth grade and is then abandoned it would seem unlikely that permanent behavior changes would result. If in future studies we confirm the hypothesis that the use of the inquiry method facilitates conceptual growth and develops inquiry skills and strategies, we should begin to investigate ways of bringing it into the curriculum.

One of the biggest dangers that accompanies each new teaching method that enjoys some measure of success is that it will be accepted rigidly and uncritically and used only in a limited sense. The Inquiry Training that was tested in this study can certainly be improved and adapted in many ways. It can be used to strengthen the curriculum in various content areas, and by the same token inquiry skills can be developed within the context of a wide variety of problems.

Our main conclusion from the test results and from our experience with Inquiry Training in many classrooms is that the technique in its present form has a marked effect on the motivation, autonomy and question-asking fluency of children. They clearly enjoy having the freedom and the power to gather their own data in their quest for assimilation.

Because they are not generally accustomed to having and exercising this freedom under ordinary circumstances in most classrooms, they have some initial difficulty making full use of it in the beginning of the training period. But, as the results clearly show, after twenty-four weeks their fluency and autonomy are far in advance of children who have not had Inquiry Training.

While we have not demonstrated this empirically, it appears to us that the following elements of the Inquiry Training program are the most critical and should be incorporated in any future attempts to develop similar classroom techniques:

1. Concrete problems that are immediately intelligible to the learner. That is, upon being presented with the problem the child should become immediately aware of just what the problem is. The first step of inquiry must be the analysis of the problem and this cannot be initiated until the problem is clearly presented. Of course the identification of problems is a legitimate activity but in our thinking it does not fall within the realm of inquiry which begins in response to the awareness of a problem.
2. Freedom to perform data-gathering operations. The programming of data intake should remain almost entirely in the hands of the inquirer. Autonomy grows as it is exercised.
3. A responsive environment. Data of the kind needed in solving the problem must be available in great abundance. It should be possible for the inquirer to obtain whatever data he wants (including irrelevant data) as easily and quickly as possible.
4. Elimination of extrinsic rewards. The motivation for inquiry

should be wholly intrinsic in the search itself. Outside pressures are likely to produce behaviors that interfere with effective inquiry. Inquiry will become more productive as the motivation of the inquirer shifts from the desire to "be right" to the desire to "find out why."

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APPENDIXES

A. Sequence of Training Films and Major Relational Constructs

B. Resumes of Test Films

C. The "Questest"

D. The P.C.E. (Predict-Control-Explain) Test

APPENDIX A

Sequence of Training Films and Major Relational Constructs

ILLINOIS STUDIES IN INQUIRY TRAINING

Revised 9/30/60-dar

Sequence of Training Films and Major Relational Constructs

* = Noncrucial relationship
** = Crucial relationship

Training Session	Film No.	Film Content	Relational Constructs (See following pages for descriptions)																									
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	10	Water Can	*					**																				
2	9	U-Tube Manometer	*	*	*	*	*	**																				
3	1	Submerged Beaker	*	**	*	*		*																				
4	21	Air Sled	*	**	*	*															**							
5	32	Surface Tension & Cheese Cloth	*			**	*								**													
6	31	Incompressibility of Water	*		**		**	*																				
7	30	Siphon	*			*	**	**																				
8	5	Balloon and Vacuum Pump	*		**	*																						
9	16	Ball and Ring	*							*	**																	
10	18	Bi-Metallic Strip	*							*	**									**								
11	25	Relative Expansion of Air and Water Under Heat	*									*	*	**														
12	3	Condensation								*				**														
13	7	Varnish Can	*	*		**				*		*	*	**														
14	6	Water Boils Under Reduced Pressure	*			*				*		*		*		**												
15	4	Pulse Glass	*	*						*		**	**	**														
16	11	Buoyancy	*	*				**	**																			
17	2	Pouring Air Upward	*	**				*	*																			
18	23	Convection	*	*					**	**	**																	
19	12	Foil Boat	*	*				**	**																			
20	20	Wood Sinks and Floats	*	*				**	**																			
21	27	Jet Powered Boat	**							*				**		*												
22	26	Water Pressure in a Closed System	*		**	*	**	*																				
23	34	Car and Inclined Plane	*																**						**			
24	35	Center of Gravity	*														**								**			
25	33	Centrifugal Force	*																					**	**			
26	34	Pendulums	*																			*			**			
27	29	Magnetic Lines of Force																**								**		
28	28	Electromagnetic Coils																*								**	**	
29	22	Bernoulli's Law	*																				**					
Test IV	19	Candle and Flask	*	*		*						**	**															**
Test I	13	Cartesian Diver	*	*	**		**	**	**																			
Test II	8	Boiling Water by Cooling	*		**	*				*	*	**	**	**		**												
Test III	14	Spinning Bucket	**					**																	*			

Relational Constructs in Inquiry Training Films

1. Newton's First and/or Third Law of Motion:

   First - An object at rest tends to remain at rest, and when in motion tends to remain in motion in a straight line, and at the same speed, unless acted upon by an unbalanced force.

   Third - To every action there is an equal and opposite reaction.

2. Displacement:

   Two objects or substances cannot occupy the same space at the same time.

3. Volume-Pressure Relationship in Gases:

   With temperature held constant, the colume and pressure of a given amount of gas (by weight) are inversely related.

4. Atmospheric Pressure:

   Air has weight. The atmosphere has depth. The pressure exerted by the air on objects in the atmosphere is a function of the depth (or altitude) at which the object is placed. It is exerted equally in all directions at any given altitude.

5. Incompressibility and Nonextendability of Liquids:

   Most liquids can only be negligibly compressed or extended by altering the pressure applied to them. They will transmit pressure equally in all directions.

6. Depth-Pressure Relationship in Liquids:

   The pressure exerted by a liquid upon objects that are immersed in the liquid is a function of the depth at which the object is placed. The pressure is exerted equally in all directions at any given depth.

7. Archimedes Principle:

   A body immersed in a liquid is buoyed up by a force equal to the weight of the displaced volume of the liquid. This force is also equal to the difference in downward and upward pressures on the immersed body that results from the difference in depth between the top and the bottom of the object.

8. Conduction of Heat:

Heat may be conducted through objects or from one object to another by direct contact. Materials vary in the rate at which they will conduct heat. (May be explained in terms of molecular motion.)

9. Temperature-Volume Relationship in Liquids and Solids:

Objects generally expand when heated and contract when cooled. (There are certain exceptions at or near the fusion point.)

10. Vapor Pressure and its Relationship to Temperature:

At the surface of liquids vapor is constantly being formed and being condensed back into liquid. For a given liquid the pressure of the vapor formed is a function of the temperature of the liquid at the surface. (i.e., each liquid has a specific vapor pressure for each temperature.) In all cases the higher the temperature the greater the vapor pressure.

11. The Temperature-Volume-Pressure Relationship in Gases (Boyle's Law):

When volume is held constant the pressure of a gas varies directly with its temperature. When pressure is held constant the volume of a gas varies directly with its temperature. When temperature is held constant the pressure of a gas varies inversely with its volume.

12. The Change of State from Gas to Liquid (Condensation) and the Reverse (Vaporization):

Most gases, if sufficiently cooled, will condense into a liquid state. When liquids vaporize they undergo enormous volume increases and require large amounts of heat. Condensation brings a volume decrease and heat is given off.

13. Surface Tension:

The molecules at the surface of a liquid are drawn more closely together to form a layer that is more difficult to penetrate than the rest of the liquid.

14. Boiling Point:

When the temperature of a liquid has been raised to the point where its vapor pressure is equal to or greater than the pressure being exerted on the surface of the liquid, the vaporization of the liquid will occur within it as well as on its surface. The temperature at which this rapid internal vaporization occurs for a given liquid is known as its boiling point. The boiling point of a liquid is a function of the pressure within the liquid.

15. Center of Gravity:

For every object there is a point at which all of its weight seems to be concentrated. One may consider that there is a downward force from this point equal to the weight of the object.

16. Magnetic Polarity:

All magnets have two poles - a north pole and a south pole. Like poles repel each other, unlike poles attract.

17. Mechanical Advantage of the Incline Plane:

An incline plane may be used as a machine to raise objects by applying less force than would be required by lifting them vertically. More gradual slopes require less force to lift an object, but do not lift them as high for any given linear distance moved.

18. Coefficient of Expansion:

Different substances expand and contract at different rates when subjected to changes in temperature.

19. Friction:

The motion of objects in contact is resisted by a force that is a function of the nature of the contact surfaces and the force exerted by one object on the other. As the latter force is increased the force of friction is also increased.

20. Conservation of Energy:

Energy is never lost. It may be transferred from one object to another or converted from potential to kinetic form and vice versa.

21. Bernoulli's Law:

The pressure of a gas exerted upon the surface of an object is a function of the motion of the gas in relation to the surface. The greater the velocity of this motion the less pressure the gas will exert upon surfaces tangential to the motion.

22. Centrifugal Force:

Objects constantly forced to move in a curved path will resist this force in an equal and opposite direction. (See Newton's First and Third Laws.) The force necessary to produce circular motion must be toward the center of the circle, and the force resisting this is in the opposite direction or away from the center of the circle. The latter force is known as centrifugal force.

23. Resultant of Forces:

When more than one force is acting on an object these can be resolved into a single force having a single magnitude and direction.

24. Lines of Magnetic Force:

Lines of magnetic force emanate from the poles of a magnet in a characteristic pattern. These lines exert a much greater force upon some substances such as iron than upon others.

25. Electromagnets:

Magnetic lines of force are produced by an electric current. When this current is passed through a coil that is wrapped around an iron core the core becomes a magnet. The strength of the magnet is a function of the amount of current passing through the coil and the number of turns of wire in the coil. The more turns the stronger the magnet.

26. Combustion or Burning is a Chemical Reaction:

When a substance burns in the presence of oxygen part of this substance usually combines with the oxygen to form a new substance. When a candle burns some of the oxygen combines with carbon in the candle to form a new gas called carbon dioxide. Some of the oxygen combines with hydrogen from the candle to form water. In combustion or any other chemical reaction no material is ever "used up," substances are merely changed in form and combined in different ways.

APPENDIX B

Resumes of Test Films

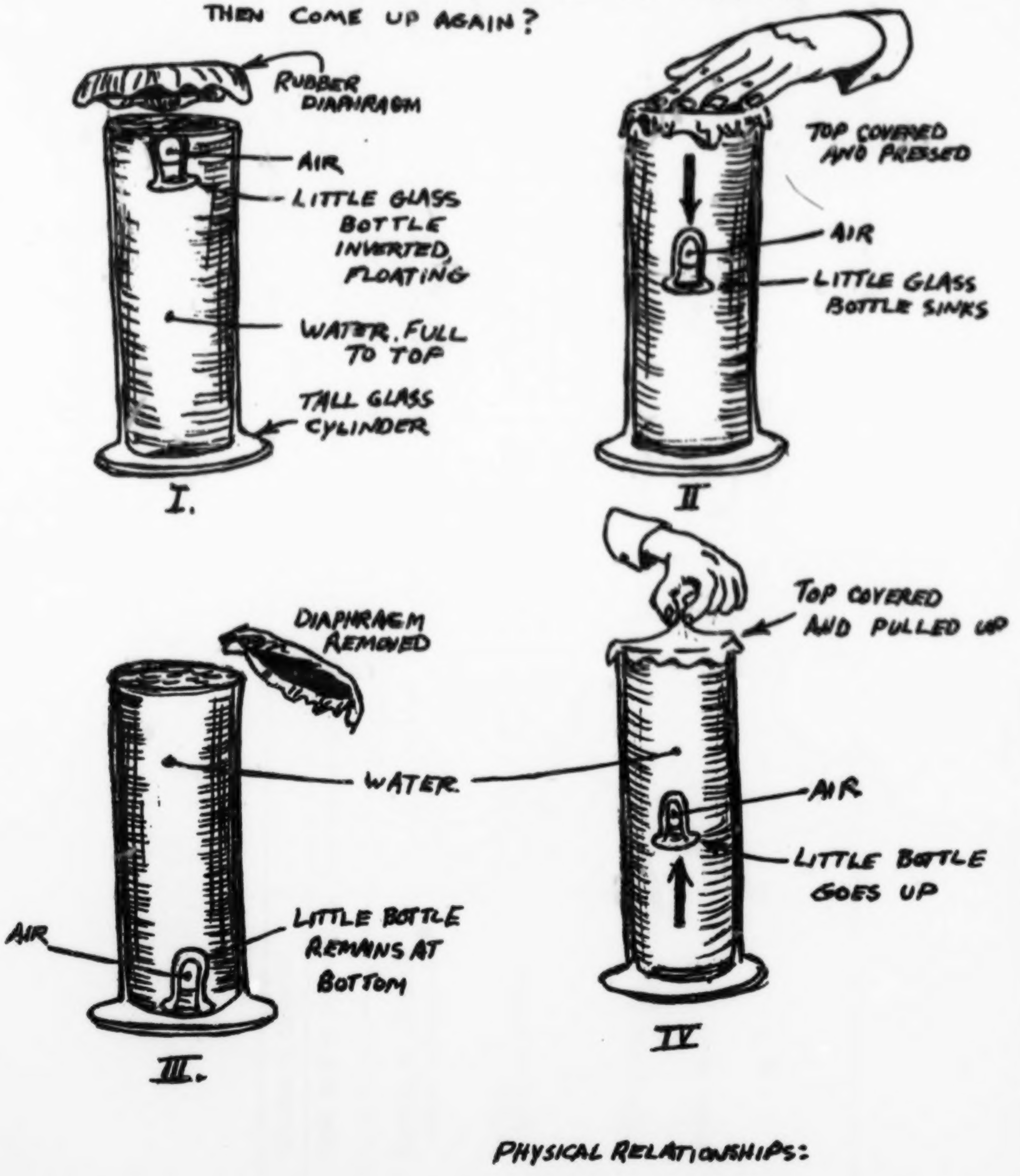
Test Film I - "Cartesian Diver"

Test Film II - "Boiling Water"

TEST FILM I

FILM NO. 13 CARTESIAN DIVER

WHY DOES THE LITTLE BOTTLE GO DOWN AND THEN COME UP AGAIN?


RUBBER DIAPHRAGM
AIR
LITTLE GLASS BOTTLE INVERTED, FLOATING
WATER. FULL TO TOP
TALL GLASS CYLINDER
I.
TOP COVERED AND PRESSED
AIR
LITTLE GLASS BOTTLE SINKS
II
DIAPHRAGM REMOVED
WATER
AIR
LITTLE BOTTLE REMAINS AT BOTTOM
III.
TOP COVERED AND PULLED UP
AIR
LITTLE BOTTLE GOES UP
IV

PHYSICAL RELATIONSHIPS:

1. xx
2. x
3. xx
5. xx
6. xx
7. xx

Film #13

Title: The Cartesian Diver

Stage I - Episode Analysis

Systems & Objects		Events - Condition		
Name and/or Properties	Starting Conditions	Rubber pushed down	Rubber removed	Rubber replaced and pulled up.
Graduated cylinder water contained	Completely filled with water.	Completely filled with water.	Completely filled with water.	Completely filled with water.
Bottle water contained	Inverted, floating at surface, nearly full of air.	Inverted, sinking, 1/4 full of water, 3/4 full of air.	Inverted, at bottom of cylinder, 1/4 full of water, 3/4 full of air.	Inverted, rising, nearly full of air.
air contained	Pressure normal.	Pressure normal.	Pressure normal.	Pressure normal
Rubber sheet	Removed from cylinder.	Stretched across mouth of cylinder to make airtight seal. Then pressed downward.	Removed from cylinder.	Stretched across mouth of cylinder to make airtight seal. Then pulled upward.

Film #13

Stage II - Necessary Conditions.

1. The necessary conditions for the bottle to sink are:

   That the gravitational pull on the bottle exceed the upward resultant force of water pressure. This is accomplished by:

   (1) Increasing the pressure on incompressible water column.

   (2) Air trapped in the bottle is compressed, bringing the top and bottom surfaces of the inverted bottle closer together, and reducing the difference between the upward and downward pressures on the bottle. (The upper surface is glass, the lower surface is air.)

   (3) When the upward resultant force is less than the gravitational pull on the bottle, the latter sinks to the bottom.

2. Necessary conditions for the bottle to stay at the bottom are:

   That the gravitational pull on the bottle continually exceed the upward resultant force of water pressure. This was accomplished when the bottle reached the bottom of the cylinder because:

   The water pressure at this depth was great enough to keep the air in the bottle sufficiently compressed to prevent the upward resultant force of water pressure on the bottle from exceeding the downward pull of gravity on the bottle.

3. Necessary conditions for the bottle to rise to the top again are:

   That the upward resultant force of the water pressure on the bottle exceed the downward gravitational pull on the bottle. This was accomplished by:

   (1) Reducing the pressure on the air trapped in the bottle by lifting the rubber, airtight diaphragm.

   (2) Air in the bottle expanded, increasing the distance between the top and bottom surfaces of the bottle-plus-air.

   (3) Resultant upward pressure of water was increased until it exceeded the downward gravitational pull.

Film #13

Stage III - Relational Constructs.

1. Balance of Forces (Newton's Second Law): The motion of an object must change if acted upon by an unbalanced force.

2. Displacement: Two objects or substances cannot occupy the same space at the same time.

3. Volume-Pressure Relationship in Gases: With temperature held constant, the volume and pressure of a given amount of gas (by weight) are inversely related.

5. Incompressibility of Water: Water cannot be compressed. Pressure applied to water in a closed system will be transmitted equally in all directions throughout the system.

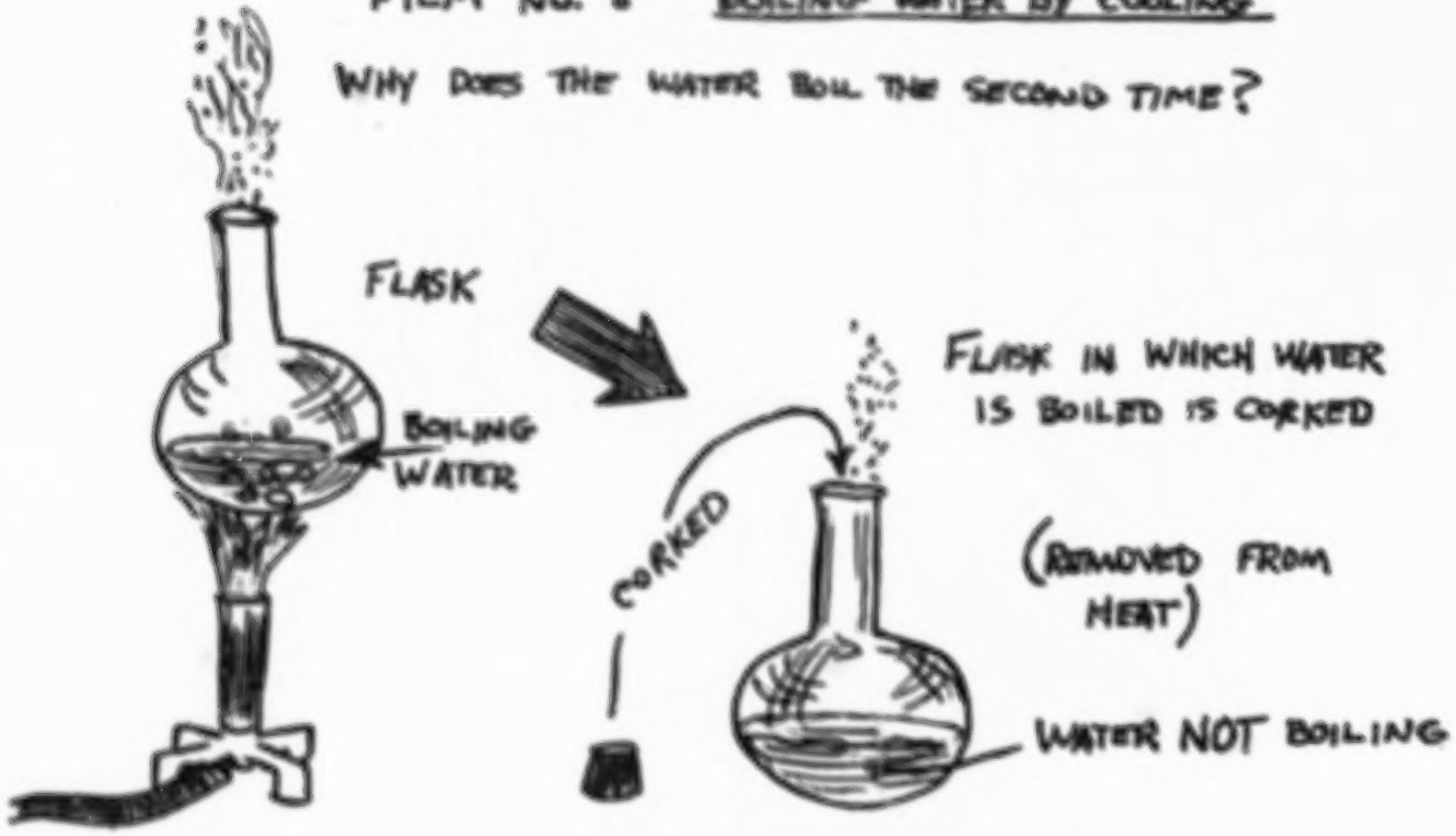
6. Depth-Pressure Relationship in Liquids: The pressure exerted by a liquid upon objects that are immersed in the liquid is a function of the depth at which the object is placed. The pressure is exerted equally in all directions at any given depth.

7. Archimedes Principle: A body immersed in a liquid is buoyed up by a force equal to the weight of the displaced volume of the liquid. This force is also equal to the difference in downward and upward pressures on the immersed body that results from the difference in depth between the top and the bottom of the object.

TEST FILM II

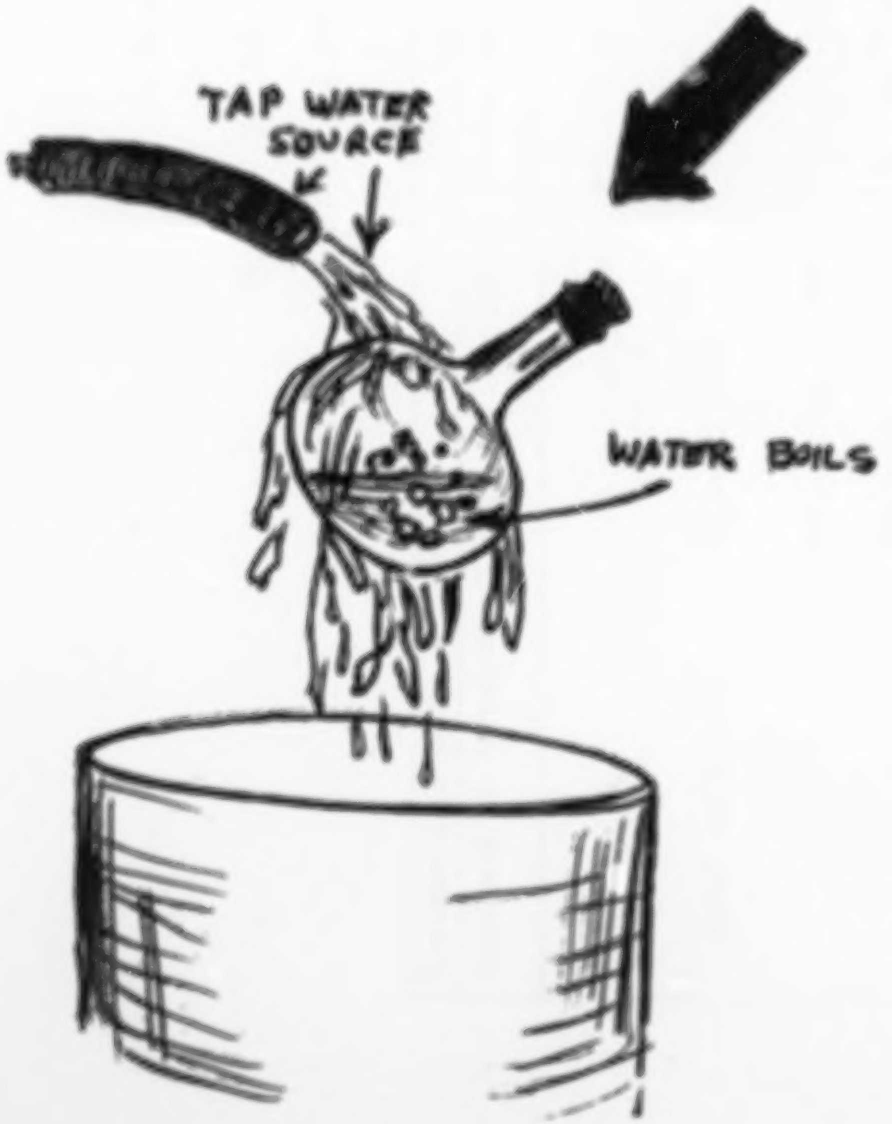
FILM NO. 8 BOILING WATER BY COOLING

WHY DOES THE WATER BOIL THE SECOND TIME?


FLASK
BOILING WATER
CORKED
WATER NOT BOILING

FLASK IN WHICH WATER IS BOILED IS CORKED

(REMOVED FROM HEAT)


TAP WATER SOURCE
WATER BOILS

CORKED FLASK CONTAINING HOT WATE IS PLACED IN STREAM OF TAP WATER.

PHYSICAL RELATIONSHIPS:

1. X
8. X
10. XX
12. XX
14. XX

Film #8

Title: Boiling Water By Cooling

Stage I - Episode Analysis

Systems & Objects	Events - Condition			
Name and/or Properties	Starting Conditions	Flask removed from heat	Flask corked	Flask held under stream of cold water
Flask	Inside pressure = 1 atmosphere	Inside pressure = 1 atmosphere	Inside pressure <1 atmosphere	Inside pressure much less than 1 atmosphere
water contained	Temp: 212°F.	Temp: nearly 212°F	Temp: less than 212°F.	Temp: much less than 212°F.
	Vaporizing rapidly.	Vaporizing rapidly.	Vapor condensing.	Vapor condensing rapidly.
	Boiling.	Not boiling.	Not boiling.	Boiling.
air contained	Displaced by H_2O vapor	---	---	---
Cork	Not in flask.	Not in flask.	In mouth of flask.	In mouth of flask.
Flame	Under flask - heating it.	Not under flask.	Not under flask.	Not under flask.

Film #8

Stage II - Necessary Conditions

The necessary conditions for the occurrence of boiling are:

That the pressure on the liquid be less than the vapor pressure of the liquid. This was accomplished as follows.

(1) Flask was heated until the vapor from the boiling water forced most of the air out of the space in the flask above the water.

(2) Flask was corked to prevent any air from returning.

(3) Flask was cooled by a stream of water. This caused the water vapor in the flask to condense (occupy less space) and reduce the pressure on the water inside the flask.

(4) When the pressure became less than the vapor pressure of the water (vapor pressure is a function of water temperature) boiling occurred.

Film #8

Stage III - Relational Constructs.

1. Balance of Forces (Newton's Second Law): The motion of an object must change if acted upon by an unbalanced force.

8. Conduction of Heat: Heat may be conducted through objects or from one object to another by direct contact. Materials vary in the rate at which they will conduct heat. (May be explained in terms of molecular motion.)

10. Vapor Pressure and its Relationship to Temperature: At the surface of liquids, vapor is constantly being formed and being condensed back into liquids. For a given liquid the pressure of the vapor formed is a function of the temperature of the liquid at the surface (i.e., each liquid has a specific vapor pressure for each temperature.) In all cases the higher the temperature the greater the vapor pressure.

12. The Change of State from Gas to Liquid (Condensation): All gases if sufficiently cooled will condense into a liquid state.

14. Boiling Point: When the temperature of a liquid has raised to the point where its vapor pressure is equal to or greater than the pressure being exerted on the surface of the liquid, the vaporization of the liquid will occur within it as well as on its surface. The temperature at which this rapid internal vaporization occurs for a given liquid is known as the boiling point. The boiling point of a liquid is a function of the pressure within the liquid.

Comments:

The key to the complete solution is the concept of vapor pressure (alien to most 6th graders) and its relationship to temperature.

Remember that different liquids, because they have different vapor pressures under identical conditions, boil at different temperatures when pressure is held constant and at different pressures when temperature is held constant.

APPENDIX C

The "Questest"

- Administration Manual
- Sample Inquiry Protocol
- Sample Items from Product Tests

THE QUESTEST

Administration Manual

A. General Aims.

1. To obtain a sample of inquiry under standardized conditions.

   It is extremely important that all the conditions of the testing situation, including the instructions given, the time allowed, the responses given to the subject's questions, and the nature and amount of reinforcement, be standardized as much as possible. The more carefully this is done, the more the test will reflect real differences among the subjects in their inquiry skills, and the less it will reflect differences produced by variations in the testing situation itself.

2. To provide data for the coding and scoring of two sets of inquiry variables.

   a. The variables of process.

   These have to do with the child's method of inquiry. They include measures of autonomy, productivity, and discipline. These scores will help to describe how a person goes about verifying and discovering the necessary facts, relationships, and concepts. These scores will be obtained by the analysis of the questions asked by the subjects as they attempt to find an explanation for the outcome of the filmed demonstration.

   b. The variables of product.

   These have to do with what the subject discovers through his questions. The scores, however, cannot be inferred from the questions and answers themselves. Three tests are used to obtain these scores. They are called Product Tests A, B, and C.

B. General Procedure.

The Questest is administered to one subject (S) at a time by a specially trained examiner (E). The test should be given in private, away from any possibility of interruption or distraction. The testing room should be equipped with a magnetic tape recorder and a 16mm. motion picture projector and screen. (Although the films to be shown are silent, they were filmed at 24 frames per second, which is the speed for showing sound films. The projector should be capable of operating at this speed.) It is desirable to be able to darken the testing room while the film is being projected.

The test procedure, which takes about thirty minutes, has four phases.

Phase I: Instructing the subject.

It is of the utmost importance that this phase be carried out properly. Most subjects have never taken a test of this kind before. They may have no idea of what is expected of them, or perhaps they will have an incorrect expectation. The instructions must be patently clear. There must be no doubt in the subject's mind when he begins the test about what he is expected to do and how it can be done.

For this reason, the instructions have been carefully prepared and should be read by E to S exactly as they are written. The examiner should become familiar with these instructions in advance to prevent any confusion during the first few tests that he gives.

There are points during the instruction phase when E must check to see that S understands what is to be done. It is vital that E do this checking with care. If S misunderstands the instructions, the entire test may be invalidated.

Questest Instructions for Use with Test Film I.

Note: Instructions which should be read to the examinee are closed in boxes. Other instructions refer to procedures involved in the test situation.

> I am going to show you a short film of a science demonstration. Watch it carefully. Your job will be to find out why the bottle goes down and why it comes up again.

Run film first time.

> Here is how you can solve the problem of why the bottle went down and why it came up again. First of all, you can ask me questions about the demonstration; about everything you just saw in the film. But they must be questions that I can answer by "yes" or "no." For example, you could ask, "Was that little bottle made out of glass?" and I would answer "Yes." The idea of asking such questions is to find out exactly what was in the film and what happened. Now, you ask me another question just like that about the demonstration.

Question is asked and answered.

You can also ask questions to find out what would have happened if things were different, and these must also be "yes" or "no" questions. For example, you might ask, "Would the bottle have gone down and up as it did if the red thing in it (or on it) were not there?" The answer would be "Yes." Then you would know that the little red thing had nothing to do with the bottle going down and up.

Check here to be sure the child understands the interpretation of the answer.

This kind of question is something like an experiment. You change something to see what happens. Now, you ask me a question like that. Remember, I must be able to answer it with a "yes" or "no."

If the child does not have the idea, explain further but do not give any further examples from this film. Other examples must be used to get the point across.

I will try to answer your questions with a direct "yes" or "no," but it may not be possible to do so without misleading you. If the answer you get is vague and incomplete it is probably because your question was not clear or complete.

Pause.

Whenever you think you know why the bottle went down or why it came up again, tell me what your explanation is. If it is completely correct, I will tell you and that will end the test. If it is not I will tell you so and you may then continue asking questions and looking for explanations until the time is up. Then you will take some tests that will give you a chance to show us what you have learned. Do you understand what you are supposed to do? All right. You may use this paper and pencil in any way that you wish during the test. I will show you the film once more and you will have 25 minutes to ask questions and try to discover why the bottle went down and why it came up again.

Show film second time.

Phase II: Presenting the problem.

The subject is instructed to formulate an explanation for a specified result of a filmed physics demonstration. The film is shown twice, once near the beginning of the instruction period, and once again at the end. It is desirable for E to have an assistant present to run the projector and rewind the film for the second showing. However, this extra person should not be present in the testing room during the Inquiry Phase. A title card on each film states exactly what the subject is expected to try to explain.

The film is not shown any more than the two required times. The subject may discover or verify more about the film's content through questions.

Phase III. Inquiry.

After he has seen the film the second time, S begins his search for the explanation of the demonstration. The instructions given in Phase I specify that only questions that can be answered by "yes" or "no" will be answered by E. If S asks another kind of question he should be reminded of this restriction.

The examiner's responses to S's questions will be "yes" or "no" wherever one of these is reasonably correct and the question is germain to the problem at hand. However, where the question is equivocal, imprecise, vague, or in some other way in need of elaboration or qualification, E offers as qualified an answer as the truth requires, suggesting that S rephrase his question with more clarity, precision, or whatever is needed.

Note that every yes-or-no question (except those that are not directly relevant to the problem itself) should be answered by E - however useless the answer may have to be. If certain questions are not answered, S may become discouraged and give up. The purpose of the Questest is to sample S's questioning. This will not be representative sample if we prohibit "bad" questions.

Main Responsibilities of the Examiner

1. To maintain rapport with S.

2. To answer S's questions when they are properly phrased and clearly understandable. When S's question is not clear, E should ask him to clarify or illustrate.

3. To give a qualified answer where necessary, stating why it cannot be more definitive.

4. To encourage S at all times and help him to minimize blocking. Reinforcement should be general ("You're doing fine" rather than specific ("That was a good question").

5. To avoid giving or suggesting to S any ideas about the film or a particular line of questioning.

Some Guiding Rules for Examiners

1. The amount of information a child is able to get from a question should be a function of the amount of precision, control, and clarity of communication the question possesses. Therefore, if you can truthfully answer a question "yes" or "no," even if it is a very broad and useless question, answer it! For example, if S asks, "Was there pressure?", don't ask him "Where?" and "When?". Say "Yes." and let him find out the other details for himself, if he wants to. As long as you understand the question as he has asked it, and you can give it a direct "yes" or "no" as it stands, that is how you should answer it.

2. If the question does not communicate, however, and the words S is using just don't fit together into a clear question, then you will have to probe further to get the child to clarify his question. For example, if he asks: "Did the suction move down and push the pressure up?", your answer should be, "I don't understand your question. What do you mean by 'suction moving down'?" Questions that do not communicate cannot be answered, and S should be asked to clarify. If he cannot do so after several tries he will probably move on to a new question. Do not help S communicate in any way. Don't put words in his mouth.

3. If you are unable to answer a question because S has not given you enough information, his question is not controlled and your correct response is, "It all depends." For example, S asks about the Cartesian Diver, "Would it work if you used something else for a cover instead of rubber?" Since he does not specify what and since certain other substances would work, you must answer, "It all depends."

4. If S asks about the "purpose" of the experimenter, or the "purpose" of the cork in the mouth of the flask, inform him that the purpose of the demonstrator or any part of the demonstration is to present him with a problem, an event that he has to explain. In other words, if S asks if the cork in the flask in Test Film II keeps the air from coming in we can answer "yes." But if he asks if the purpose of the cork is to do this, we do not give the direct answer. The reason for this evasion is to prevent S from doing the worst kind of brain picking by getting at the demonstrator's objectives rather than the necessary conditions.

5. If S asks if something "has anything to do with" something else, answer the question if you can, and give it a very broad and liberal interpretation. If he asks, "Does the bottle going up and down have anything to do with pressure?" the answer is "yes." But if something (like the red spot on the bottle) is clearly irrelevant, answer, "No."

6. Just a word about explanations and what you should do about them. When an explanation is stated as such, hear it out. If it is

complete and correct tell S so and dismiss him. (This eventuality is extremely unliekly.) If the explanation is correct but not complete, tell him that everything he has said is correct but he has not given the whole explanation. Tell him to keep going. If any part of his explanation is not correct, simply tell him that his explanation is not correct.

Phase IV: Testing for Product Variables.

A. The Tests.

Product Test A is a test of the comprehension of the physical principles in the test film.

Product Test B measures the child's ability to identify the the necessary conditions for the events in the film to occur.

Product Test C measures the child's knowledge of the objects, events and conditions of the test film.

B. Procedure for Administering the Product Tests.

Product Test A should be given the first time in advance of the inquiry period. As soon as S has completed his inquiry session he must be given the three Product Tests. There is no time limit. It is important that S does not talk to anybody. He must finish one test and turn it in before he takes the next. Supply colored pencils and do not allow S to change his answers.

Questest Protocol Excerpt # I

Unit No	Verbatim Record	Question Types
1.	E*: Okay you may begin. S**: Is that a special kind of chemical in the glass tube? E: Could you tell me what you mean by a special kind of chemical, I think that the answer is no, but I want to find out. S: Well, is it a chemical to make it do this? E: No.	Verification/categorical/normative
2.	S: Well then, let's see. Is the bottom of the little glass bottle open? E: Yes.	Verification/analytical/condition-descriptive
3.	S: Then would it be pressure that would pull and make it go down? E: Ah, Pressure--pressure has something to do with it yes. Go ahead, I am just going to draw a diagram so you can point-here and tell me what it is.	Implication/abstract-conceptual/directed
4.	S: That, that, the rubber--that is rubber that they used on the top? E: Yes! On the top.	Verification/categorical/nominal

* E: Examiner

**S: Subject

	S: Well then, I think that it when if pressure has something to do with it when you push it down-- it would-- the pressure would make the bottle go down and then she-- when she pulled up it would make it come up. E: Yes that had something to do with it. That is not the whole explanation.	Explanation
5.	S: And the bottom is open then the water would go up in the bottle, wouldn't it? E: When?	Verification/analytical/condition-descriptive
6.	S: When it was going down wouldn't the water coming up in it. No; that wouldn't make it go down, would it? Does that water have to be hot or cold or? E: No.	Implication/concrete-conceptual
7.	S: Not especially. The tube is glass, I know that much Does it have to do with any certain amount of water? E: I don't know what you mean by "any certain amount of water". S: Well, would it, would they have to have a certain amount of water for it to do this? E: Yes, that would affect it, the amount of water that you have in there.	Implication/concrete-conceptual

8.	S:	Does it have anything to do with the thickness of the rubber?	Implication/abstract-conceptual/diffuse
	E:	Not very much, no.	
	S:	I think that I know...	
	E:	Do you want to give an explanation?	
	S:	Well...	
	E:	Anytime that you want you can.	
	S:	Usually when you have a straw or something and when you put your finger on it... it will come up. Well I am not sure what it does.	
9.	S:	Let me see...(mumbling).. (pause) Pressure has something to do with it?	Implication/abstract-conceptual/diffuse
	E:	Yes.	
10.	S:	Is the water distilled?	Verification/analytical/condition-descriptive.
	E:	No.	
	S:	I can't think of any reason for it to go up or down, except for the pressure. (Pause). Oh, I don't know.	

Questest Protocol Excerpt # 2

Unit No	Verbatim Record	Question Type
	E: Okay start asking questions.	Verification/analytical/condition-descriptive
	S: Is the little red thing hollow inside?	
1.	E: Do you mean inside the bottle?	
	S: Yes, the little red thing in the bottle is it hollow inside?	
	E: No.	
	S: Was she putting pressure when she shoved down on the rubber?	Verification/analytical/condition-descriptive
	E: Putting pressure on what?	
	S: The air inside of the thing.	
	E: Yes.	
	S: And when she pulled up would she have let the air--release the pressure on the air?	Verification/analytical/condition-descriptive
	E: Yes, she would have reduced the pressure on the air.	
	S: Would that be why the little bottle went down when she pressed down on it she was putting pressure and making the little bottle go down?	Implication/abstract-conceptual/directed
	E: Well the putting pressure had something to do with making the little bottle go down.	

S: Was there air inside the bottle?

Verification/analytical/structural-component

E: Yes.

S: Would air go through the rubber thing she had stretched over...

Verification/analytical/properties check

E: No.

S: Is the little...oh... that hasn't nothing to do with it. If the bottle didn't have air in it would the..(mumbles)...

Implication/concrete-inferential/experimental/elimination

E: If the bottle didn't have air in it would the experiment do what?

S: Would the experiment work without air in the bottle?

E: No.

(25 second pause)

S: If there wasn't--if the air wasn't--if there wasn't air in the whole container--in the container--the space you know the level of water-- if there wasn't air in there would the experiment work?

Implication/concrete-inferential/experimental/elimination

E: Yes.

S: It would.

E: Yes. Let me just draw a picture of the apparatus so that you can point to things when you want to. That is the thing around the top here. And here is the base of it. You can also use the rest of the paper too. Just keep it there so you can point to it when you want.

S: Well, was there anything tied onto the bottle?

Verification/analytical/structural-component

E: No.

S: Was there any suction when she pressed down--when she pulled up on it?

Verification/analytical/condition-descriptive

E: Yes, I guess. Could you tell me a little bit what you mean by suction?

S: Well like letting the air loose all of a sudden and it gets more room and it just moves up.

E: Yes. The answer is yes.

S:

S: Would that affect the bottle moving up in any way?

Implication/abstract-conceptual/diffuse

E: Yes, it would have something to do with it.

S: Was everything used made of rubber,glass-- rubber and glass?

Verification/analytical/structural-component

E: No.

S: I mean rubber and glass and water?

E: No.

S: Could you do the same experiment without the rubber and using your hand?

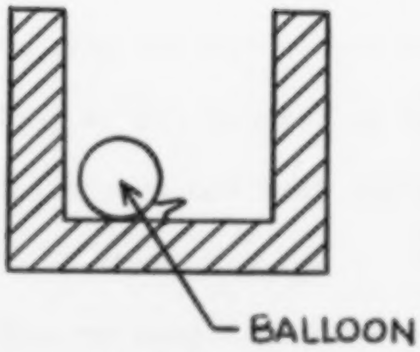
Implication/concrete-inferential/experimental/elimination

E: It's possible.

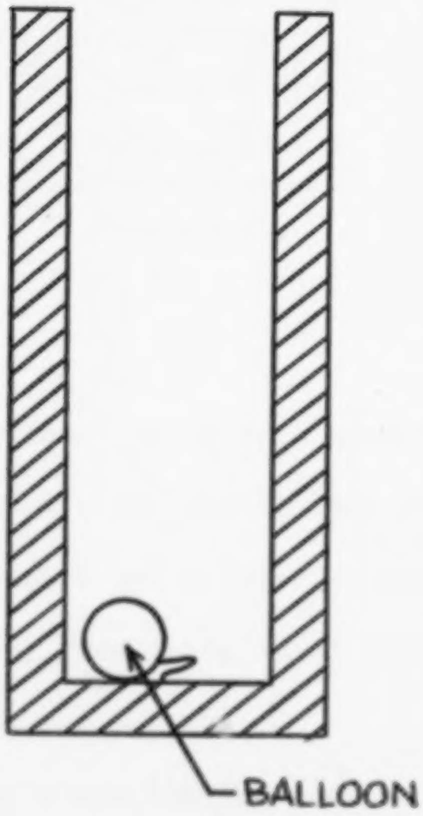
S: Was there any trick to this-- has to be a special thing or it wouldn't work? E: This is a hard question to answer.We're not trying to trick you. I know what you are thinking of.Hidden special things like little tricky... S: Yeh. E: No, nothing that you would consider a trick. All the things there are there, ordinarily.	Miscellaneous
S: Well then I guess I think the theory is that when you release--when you put down pressure it forces the bottle down,when you put your hand on the rubber it forces the air and squeezes it more together and puts pressure on the water and the bottle and makes it go down and when you lift up the sort of suction I said would bring it up	Explanation

Sample page from Product Test A, Form CD.

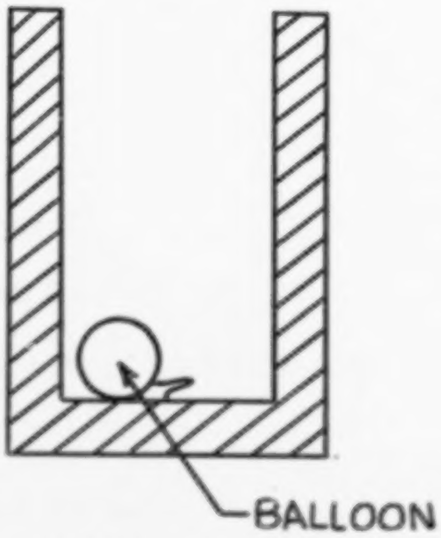
Below you see three buckets. We have three balloons that are filled with air. The balloons are exactly the same size and shape. Each balloon is tied very tightly. No air can leave and no water can get into the balloons. We tie a balloon to the bottom of each of these three buckets. Then we fill the buckets up to the top with water.



PICTURE A



PICTURE B



PICTURE C

6. If we measure the balloons after the water is all in, which balloon will be the biggest?

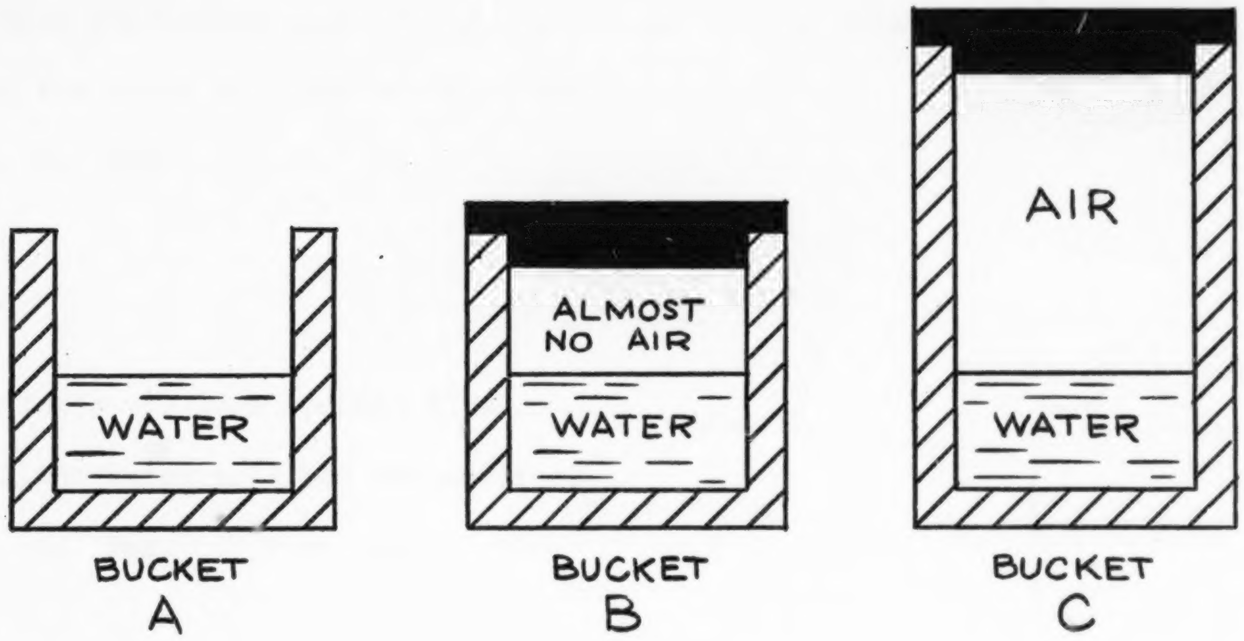
   a. The balloon in Picture A will be the biggest one. It will take up the most space.

   b. The balloon in Picture B will be the biggest one. It will take up the most space.

   c. The balloon in Picture C will be the biggest one. It will take up the most space.

   d. All three balloons will be exactly the same size. They will all take up exactly the same amount of space.

Look at the three buckets.


WATER
BUCKET
A
ALMOST
NO AIR
WATER
BUCKET
B
AIR
WATER
BUCKET
C

Exactly the same amount of water is in each bucket.

We take the air out of bucket B and put it into bucket C.

Then we put a cover on bucket B and a cover on bucket C.

The covers now keep anything from going in or coming out of bucket B and bucket C.

Then we heat each bucket with exactly the same amount of heat.

3. When will the water boil?

   a. It will boil first in bucket A.

   b. It will boil first in bucket B.

   c. It will boil first in bucket C.

   d. It will boil at exactly the same time in all three buckets.

Sample page from Product Test B, Form BW.

1. This is a special flask.

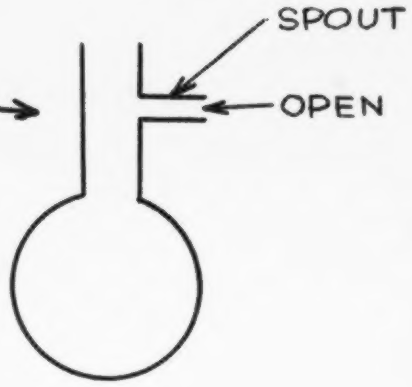
   It has a spout which is open.

   Suppose we use it INSTEAD of the flask in the film.

   We keep everything else the same as it was in the film.

   Will the water boil the second time?

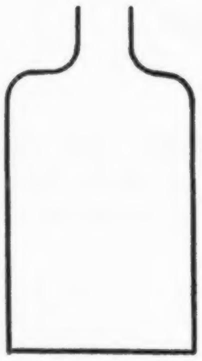
   a. Yes. b. No.



2. Now let's try this special flask.

   Will the water boil the second time?

   a. Yes. b. No.



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3. This is a rubber stopper.

   It fits tightly into the top of the flask.

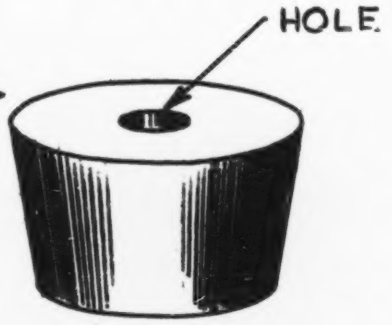
   There is a hole in the middle of the stopper.

   Suppose we use the rubber stopper INSTEAD of the cork in the film.

   We keep everything else the same as it was in the film.

   Will the water boil the second time?

   a. Yes. b. No.

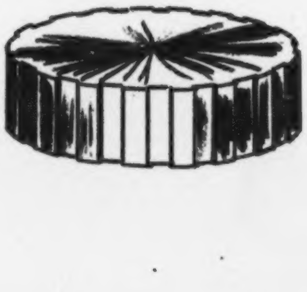


4. Now let's try this steel cap.

   When it is screwed on the top of the flask nothing can go in or come out of the flask.

   Will the water boil the second time?

   a. Yes. b. No.



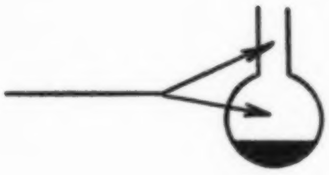
Sample page from Product Test C, From BW.

1. What was the question shown on the screen at the beginning of the film?

   a. What made the water boil the second time?
   b. Why did the flask boil the second time?
   c. Why does the water boil the second time?
   d. Why does the water in the flask boil the second time?

2. Were there any lines on the flask? a. Yes b. No

3. What was in the part of the flask above the water level before the beginning of the film, before the flask was even heated?



   a. It was all filled with air.
   b. It was filled mostly with air mixed with a little steam (or water vapor).
   c. It was mixed half with air and half with steam (or water vapor).
   d. It was filled mostly with steam (or water vapor) mixed with a little air.
   e. It was all filled with steam (or water vapor).
   f. It was completely empty.
   g. None of these is correct.

4. When was the water in the flask hotter?

   a. When the flask was being heated.
   b. When the cork was being put in.
   c. It was exactly the same temperature at both times.

5. When was the water in the flask hotter?

   a. When the flask was being heated.
   b. When the water was being poured on the flask.
   c. It was exactly the same temperature at both times.

6. When was the water in the flask hotter?

   a. When the cork was being put in.
   b. When the water was being poured on the flask.
   c. It was exactly the same temperature at both times.

APPENDIX D

The Predict-Control-Explain Test

THE P.C.E. TEST

of

PHYSICS CONCEPTS

FORM I
1960 Edition

Devised by

J. Richard Suchman and James L. Fejfar

This is a research instrument of the

ILLINOIS STUDIES IN INQUIRY TRAINING*

J. Richard Suchman, Director

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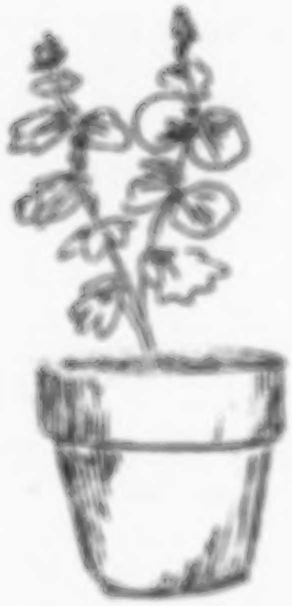
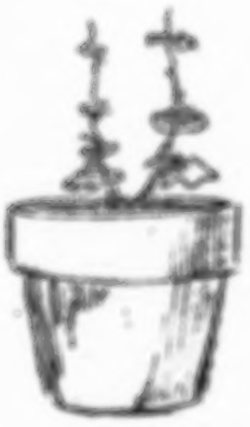
*The Illinois Studies in Inquiry Training is a research project sponsored by the Office of Education of the U.S. Department of Health, Education and Welfare and the University of Illinois.

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

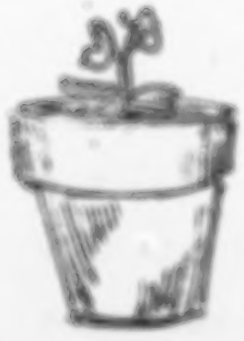
SAMPLE PROBLEM



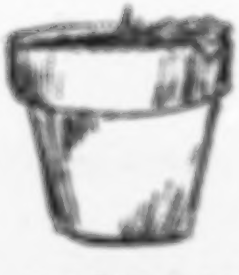
EXPERIMENT 1



EXPERIMENT 2.



EXPERIMENT 3.



EXPERIMENT 4

All of the plants in the above experiments are of the same type and all have been getting the same amounts of air, water, and food.

Sample Problem

Part A. Which of the plants would you predict is getting enough sunlight?

1. The plant in Experiment 1.
2. The plant in Experiment 2.
3. The plant in Experiment 3.
4. The plant in Experiment 4.
5. All of them.

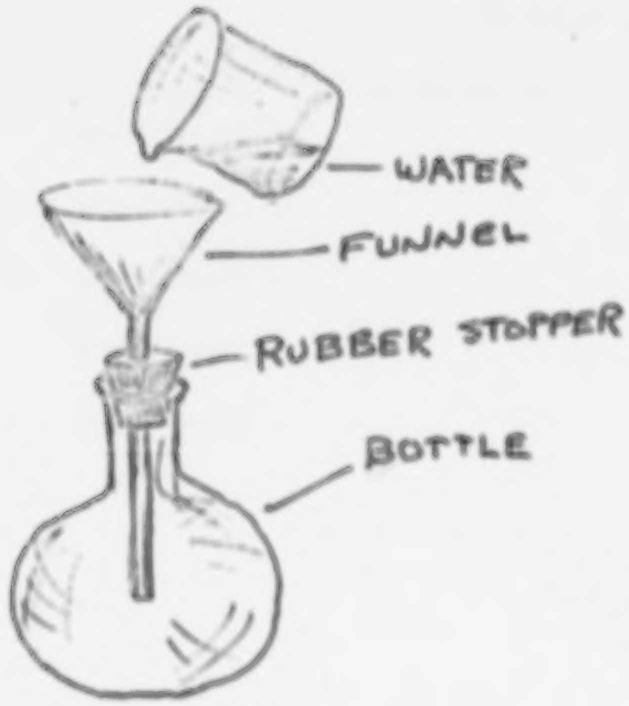
Part B. One way to make the plant in Experiment 1 look like the plants in the other experiments would be to:

1. Put it in a larger flower pot.
2. Put it in a dark room and leave it there.
3. Give it more sunshine.
4. Give it more moonlight.

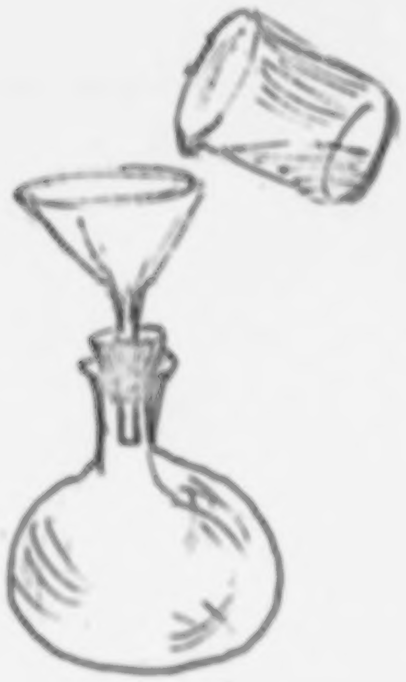
Part C. Which of the following explains the correct answers to Parts A and B?

1. Plants need water in order to grow.
2. Plants need air in order to grow.
3. Plants need light in order to grow.
4. Plants need black soil in order to grow.

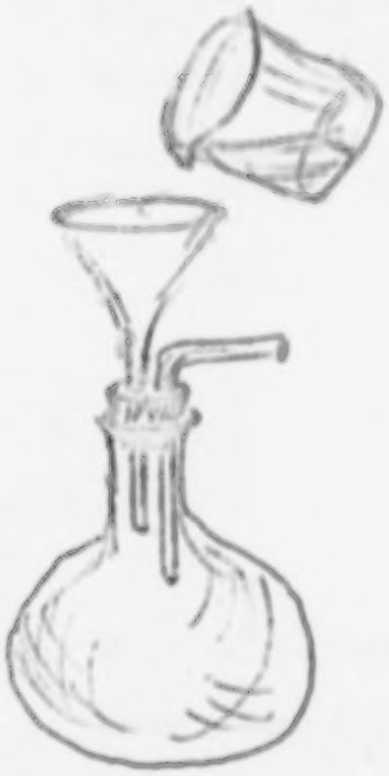
PROBLEM I


WATER
FUNNEL
RUBBER STOPPER
BOTTLE

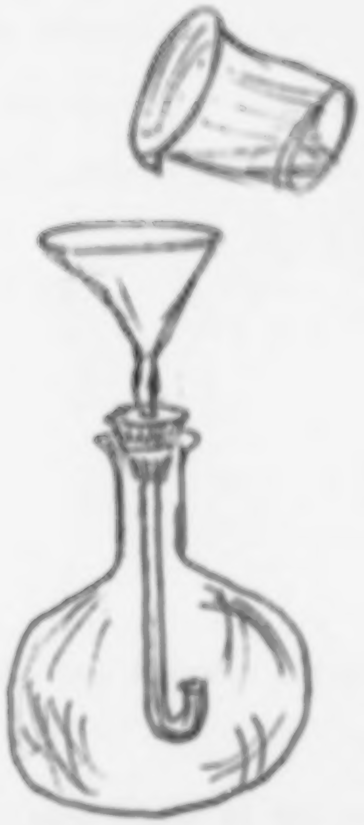
EXPERIMENT 1.



EXPERIMENT 2.



EXPERIMENT 3.



EXPERIMENT 4

In each of the above experiments, water is to be poured through the funnel into the bottle.

Problem I

Part A. In which of the experiments will the bottle fill up with water most quickly?

1. Experiment 1.
2. Experiment 2.
3. Experiment 3.
4. Experiment 4.

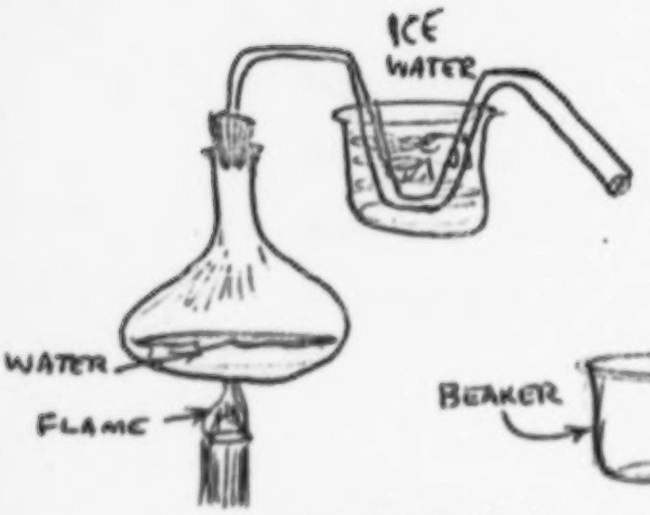
Part B. Which of the following is necessary for the bottle to fill up with water?

1. The cork must fit tightly into the mouth of the bottle.
2. The liquid must be water or some other liquid that absorbs air.
3. There must be some way for the air in the bottle to escape.
4. The bottom of the funnel tube must always be higher than the water level in the bottle.

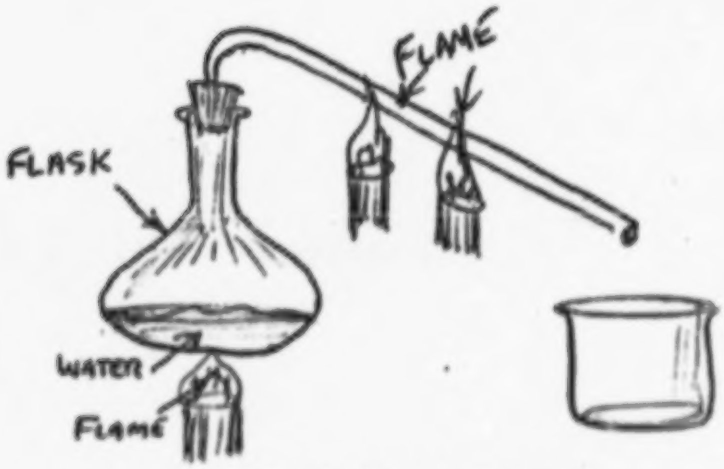
Part C. Which is the best rule to explain the correct answers to Parts A and B?

1. Water always flows down hill.
2. Water and air cannot occupy the same space at the same time.
3. Air absorbs water.
4. The flow of water is always from a high pressure to a low pressure.

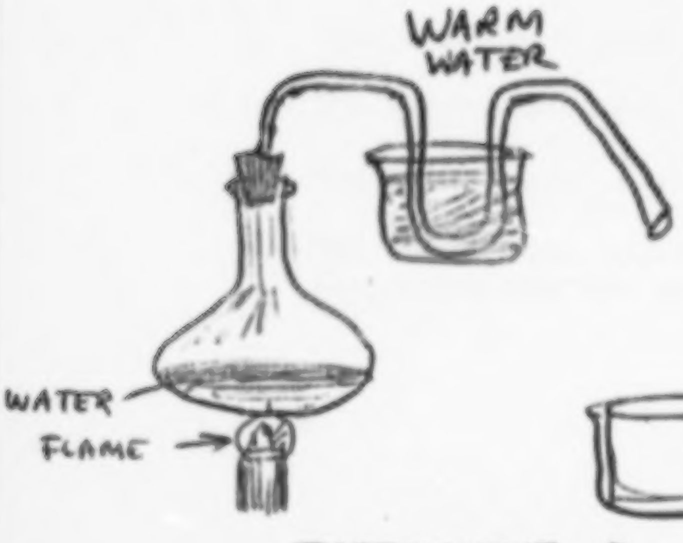
PROBLEM II


ICE
WATER
WATER
FLAME
BEAKER

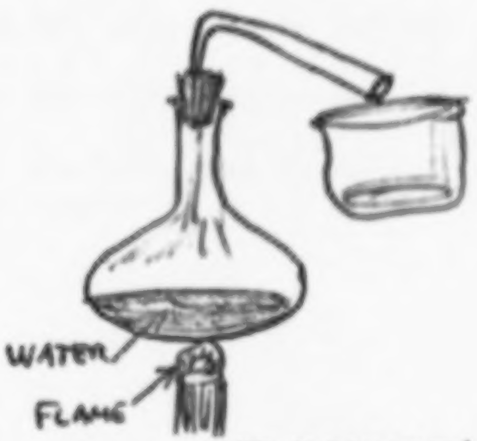
EXPERIMENT 1.


FLAME
FLASK
WATER
FLAME

EXPERIMENT 2


WARM
WATER
WATER
FLAME

EXPERIMENT 3.


WATER
FLAME

EXPERIMENT 4.

Four experiments are shown in which a flask of water is to be heated for ten minutes over a flame. Each flask has a stopper with one hole in it. A tube leads from the stopper to a beaker.

In Experiment 1, the tube passes through a can of ice water.

In Experiment 2, the tube is heated by another flame.

In Experiment 3, the tube passes through some warm water.

In Experiment 4, the tube is surrounded by the air in the room which is at a temperature of 75°.

Problem II

Part A. In which experiment will the beaker collect the most water?

1. Experiment 1.
2. Experiment 2.
3. Experiment 3.
4. Experiment 4.
5. No water will be collected in any of the experiments.

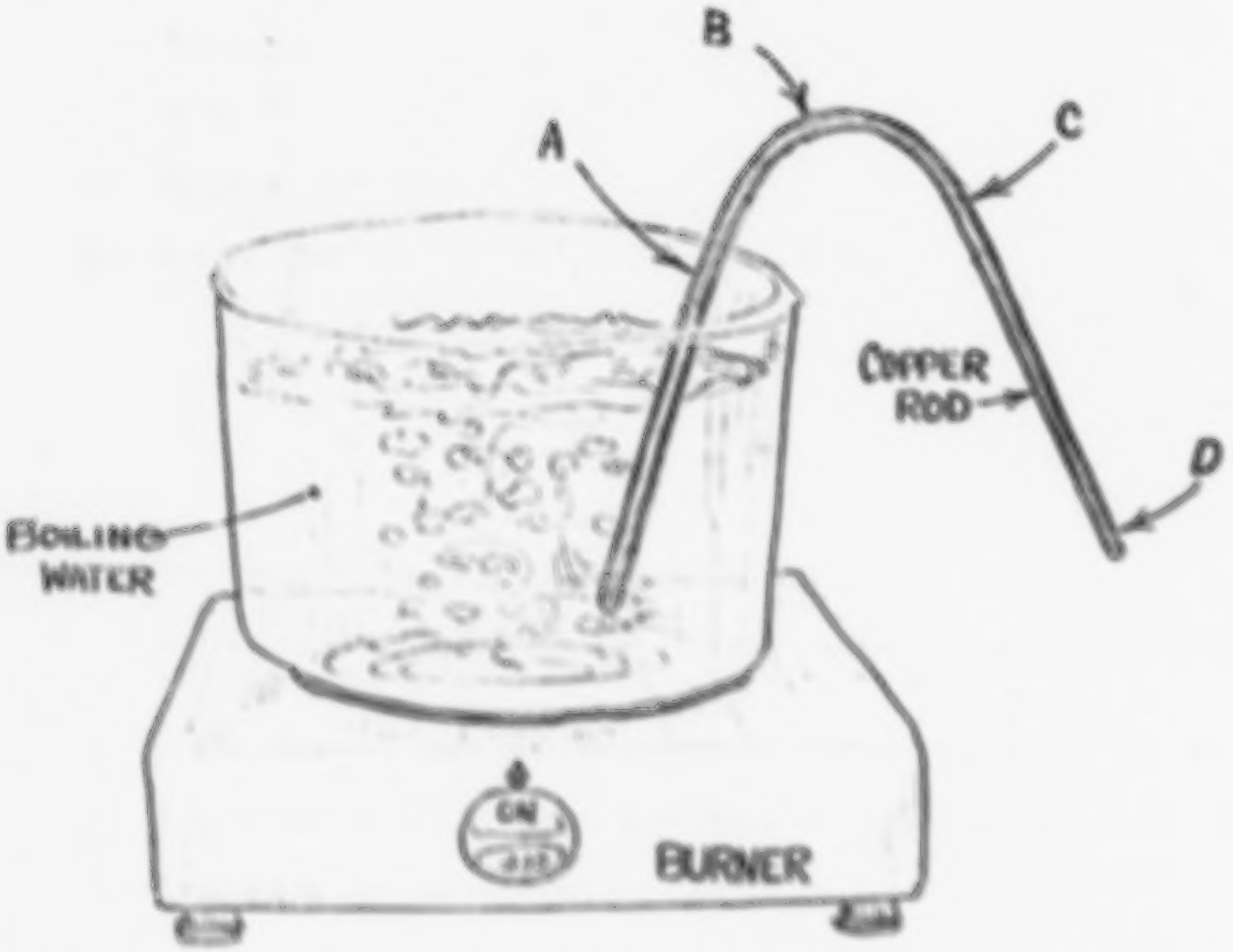
Part B. Which of the following is necessary in order to collect water in the beaker?

1. The water vapor passing through the tube must be cooled.
2. The water vapor passing through the tube must be warmed.
3. The water vapor passing through the tube must be made very hot.
4. The water vapor passing through the tube must be kept at the same temperature as the water in the flask.

Part C. Which of the following best explains the correct answers to Parts A and B?

1. Liquids may be changed into vapor by heating and changed back into liquids by cooling.
2. Liquids may be changed into vapor by lowering the air pressure and changed back into liquids by raising the air pressure.
3. Liquids may be changed into vapor by heating and changed back into liquids by more heating.
4. Temperature has nothing to do with changing a liquid to a vapor and a vapor to a liquid.

PROBLEM III


B
A
C
COPPER ROD
D
BOILING WATER
ON
OFF
BURNER

A bare copper rod which is at room temperature is bent into the form shown by the picture and one end is put into boiling water.

Problem III

Part A. Which point on the rod will get hot first?

1. Point A.
2. Point B.
3. Point C.
4. Point D.
5. All of them will get hot at the same time.

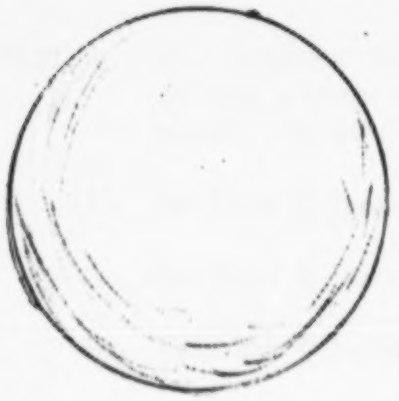
Part B. How could you make C become hot before B?

1. By taking out the end of the rod that is in the water now, and putting the other end of the rod in the water instead.
2. By keeping the same end in the water and straightening out the rod.
3. By blowing on the metal at B to keep it cool until C got hot first.
4. By leaving the experiment just as it is.

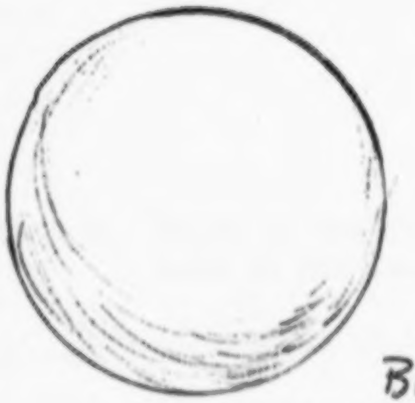
Part C. Which of the following best explains the correct answers to Parts A and B?

1. Heat rises.
2. Heat travels through air easier than through metals.
3. Heat is always conducted in straight lines.
4. Heat will travel from one point in a conductor near a source of heat to other points in that conductor that are farther away from the source of heat.

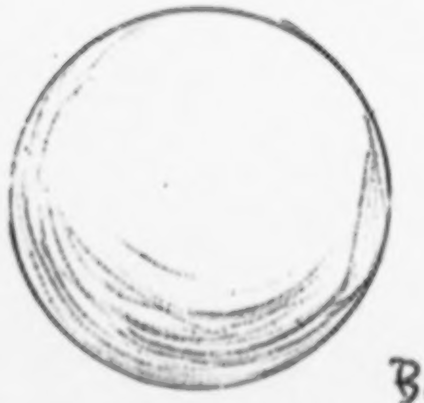
PROBLEM IV



BALLOON A



BALLOON B



BALLOON C

Three identical balloons are inflated equally with air at a temperature of 70°.

The air in Balloon A is kept at 70°.

The air in Balloon B is warmed to 140°.

The air in Balloon C is cooled to 0°.

Problem IV

Part A. If, without changing anything else, we made careful measurements of the sizes of the balloons after the temperature changes took place, we would find that:

1. Balloon B became larger than Balloon A.
2. Balloon B became smaller than Balloon A.
3. Balloon C became larger than Balloon B.
4. All balloons stayed the same size as when the temperature was 70°.

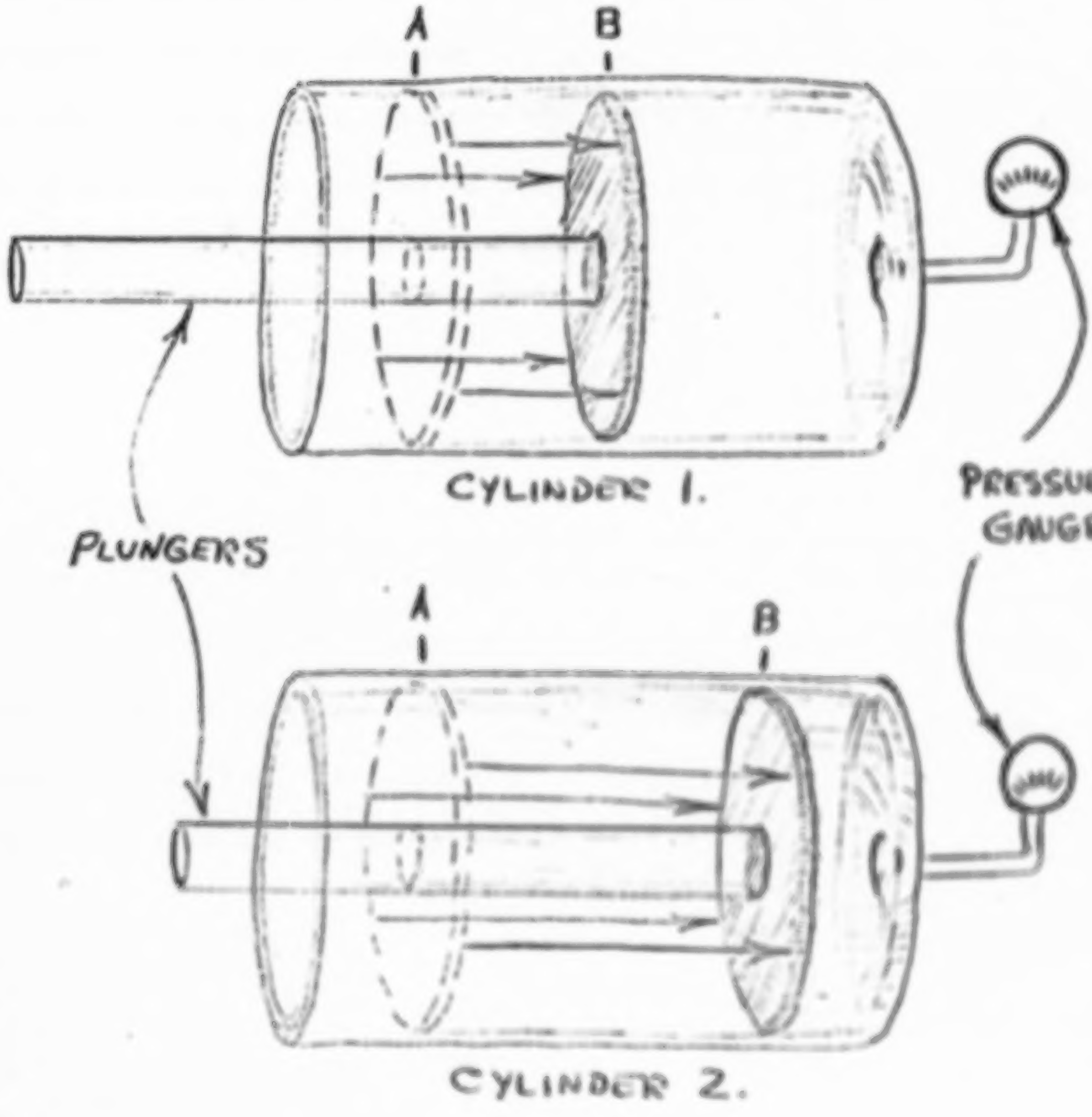
Part B. Which of the following changes in the conditions of a balloon would make it get larger?

1. Air inside is warmed.
2. Air inside is cooled.
3. Air inside is lowered to less than 0°.
4. The air pressure surrounding the balloon is made greater.

Part C. Which of the following best explains the correct answers to Parts A and B?

1. Temperature cannot affect the volume of a gas.
2. When temperature is raised, volume becomes greater if everything else stays the same.
3. When temperature is raised, volume becomes less if everything else stays the same.
4. When temperature is lowered, volume becomes greater if everything else stays the same.

PROBLEM V


A
B
CYLINDER 1.
PLUNGERS
PRESSURE GAUGES
A
B
CYLINDER 2.

The plungers in both of the air-tight cylinders in the diagrams started out at position A. The plunger in each cylinder was then pushed in to the positions marked B and the pressure gauges were read to see if there had been any change in the air pressure inside of the cylinders.

Problem V

Part A. Which of the following describes the readings of the gauges after the plungers are in position B?

1. Both show the same pressure as when plungers were in position A.
2. Cylinder 1 has a greater pressure reading than Cylinder 2.
3. Cylinder 2 has a greater pressure reading than Cylinder 1.
4. The pressure becomes greater in both cylinders but they are still equal.

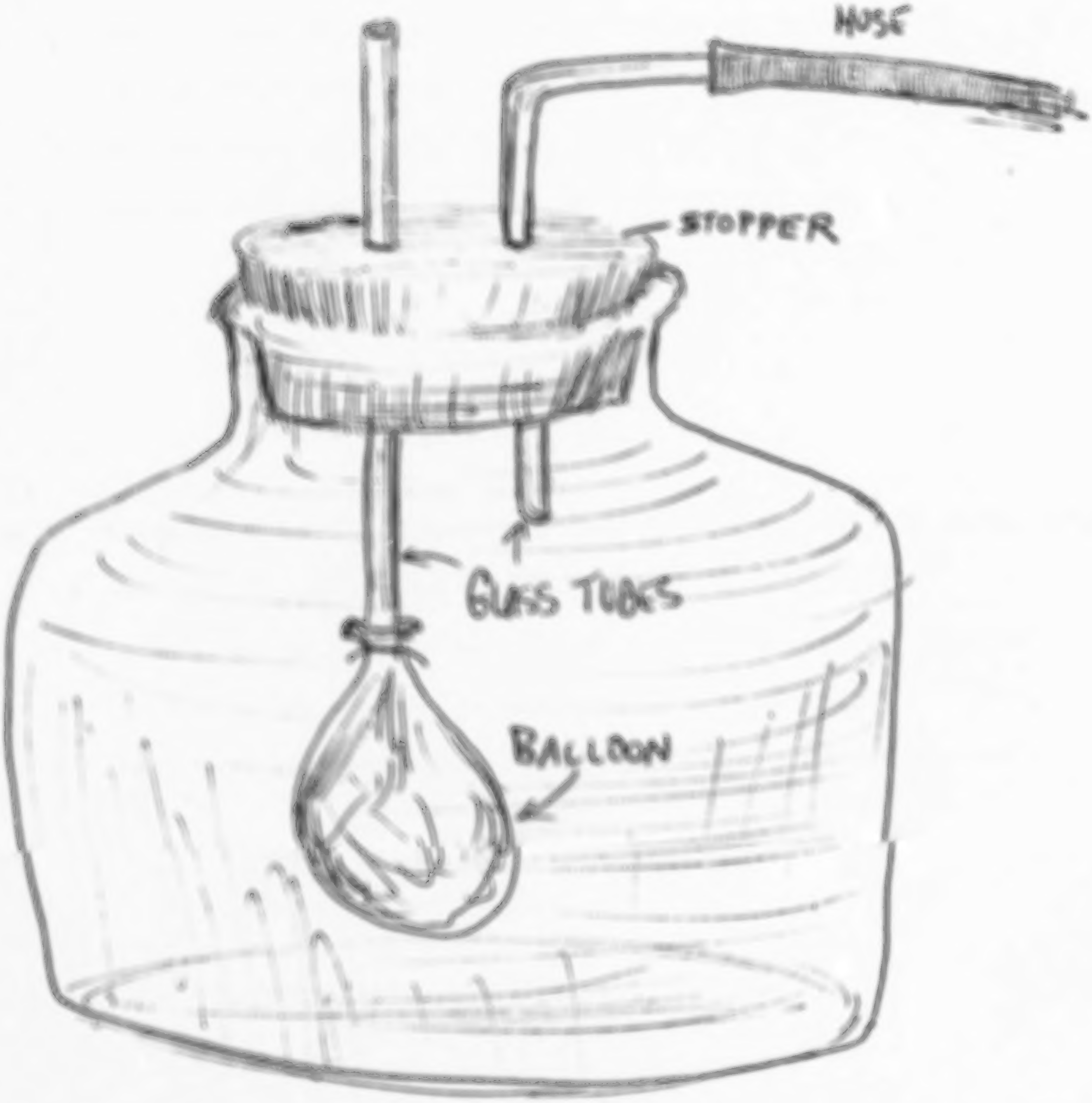
Part B. Which one of the following changes would lower the pressure of the air in the cylinder of the type shown if nothing else were changed?

1. Make the amount of space that the air occupies greater.
2. Make the amount of space that the air occupies less.
3. Change the shape of the cylinder.
4. Start with more air in the cylinder.

Part C. Which of the following best explains the correct answers to Parts A and B?

1. Pressure of gas in a container has nothing to do with the amount of space inside the container.
2. Pressure of gas in a container becomes less as the amount of space inside the container becomes less.
3. Pressure of gas in a container becomes less as the amount of space inside the container becomes greater.
4. Pressure of gas in a container always becomes greater when you change the amount of space inside the container.

PROBLEM VI


HOSE
STOPPER
GLASS TUBES
BALLOON

A large jar has a two-hole stopper. A glass tube passes through each hole. One tube is connected to a hose outside the jar, the other to a balloon inside the jar.

Problem VI

Part A. If you were to pump out air through the hose, what would happen to the balloon?

1. Balloon would collapse completely.
2. Balloon would not change.
3. Balloon would get larger.
4. Balloon would get smaller.

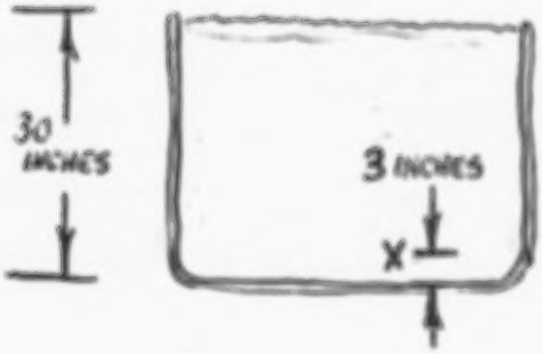
Part B. Which of these is necessary in order to make the balloon become larger?

1. Air must be forced into the balloon by someone blowing.
2. All air in the jar must be removed.
3. The air in the jar must be compressed to start with.
4. There must be a passageway between the balloon and the air outside the jar.

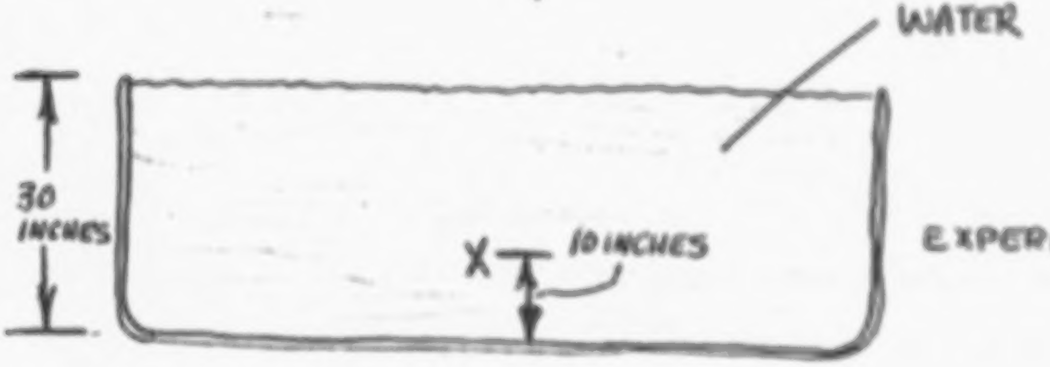
Part C. Which of the following best explains the correct answers to Parts A and B?

1. When the air is pumped out of the jar, atmospheric pressure makes the balloon get larger.
2. When the air is pumped out of the jar, suction collapses the balloon.
3. When air is pumped out of the jar, the pressure inside the balloon becomes greater.
4. When air is pumped out of the jar, the pressure inside the balloon becomes less.

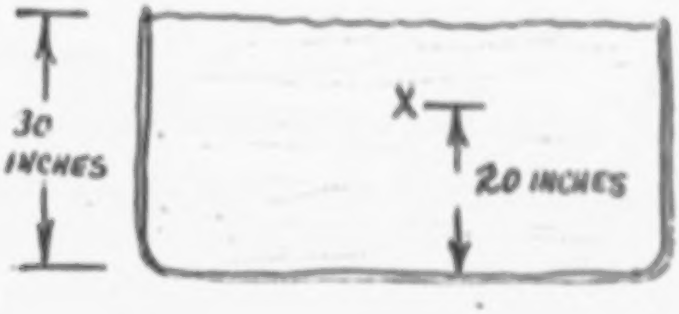
PROBLEM VII


30 INCHES
3 INCHES
X

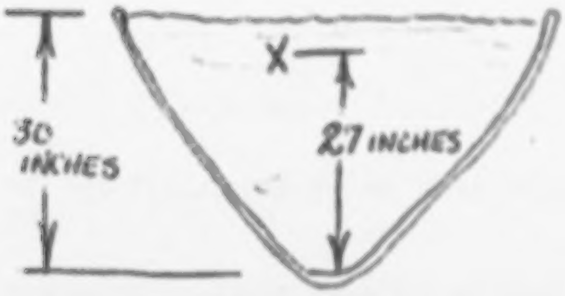
EXPERIMENT 1.


WATER
30 INCHES
X
10 INCHES

EXPERIMENT 2.


30 INCHES
X
20 INCHES

EXPERIMENT 3.


30 INCHES
X
27 INCHES

EXPERIMENT 4.

Four balloons which are exactly alike are filled with equal amounts of air and are placed in tanks of water and held in the positions shown by the X's in the drawings.

Problem VII

Part A. In which experiment would the balloon be the smallest?

1. Experiment 1.
2. Experiment 2.
3. Experiment 3.
4. Experiment 4.
5. Balloons would be the same size in all experiments.

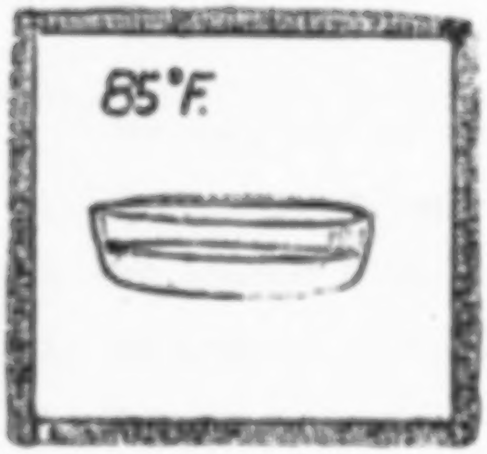
Part B. Under which of the following conditions would a balloon become smallest?

1. At the greatest distance beneath the surface of the water.
2. At the greatest distance from the bottom.
3. In the very center of the tank where pressure from all directions is equal.
4. In the tank that has the most water.
5. There are no conditions which would make a balloon smaller.

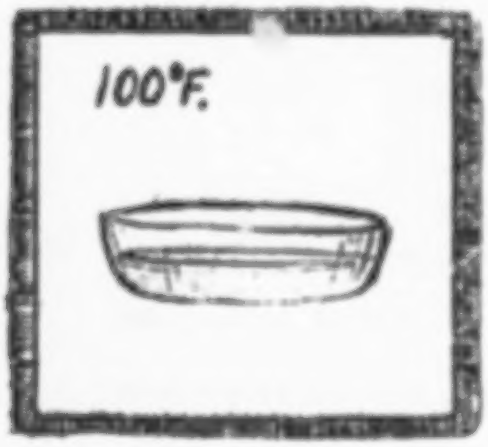
Part C. Which of the following rules best explains the correct answers to Parts A and B?

1. Water pressure becomes greater as depth becomes greater.
2. Water pressure becomes greater as depth becomes less.
3. Water pressure depends on the width of the container.
4. Water pressure is the same at all points within an open container.

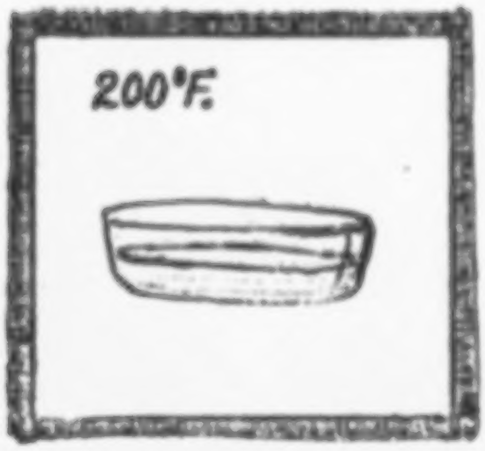
PROBLEM VIII



EXPERIMENT 1.



EXPERIMENT 2.



EXPERIMENT 3.

Bowls which are equal in all respects and which contain equal amounts of water are placed in air-tight ovens which contain dry air. The ovens are adjusted so that they remain at the indicated temperatures for one hour. The ovens are then turned off and allowed to cool to the room temperature (75°).

Problem VIII

Part A. When all the ovens have cooled down, the total amount of water in the ovens will be:

1. The greatest in Experiment 1.
2. The greatest in Experiment 2.
3. The greatest in Experiment 3.
4. The amount of water will be the same in all experiments.

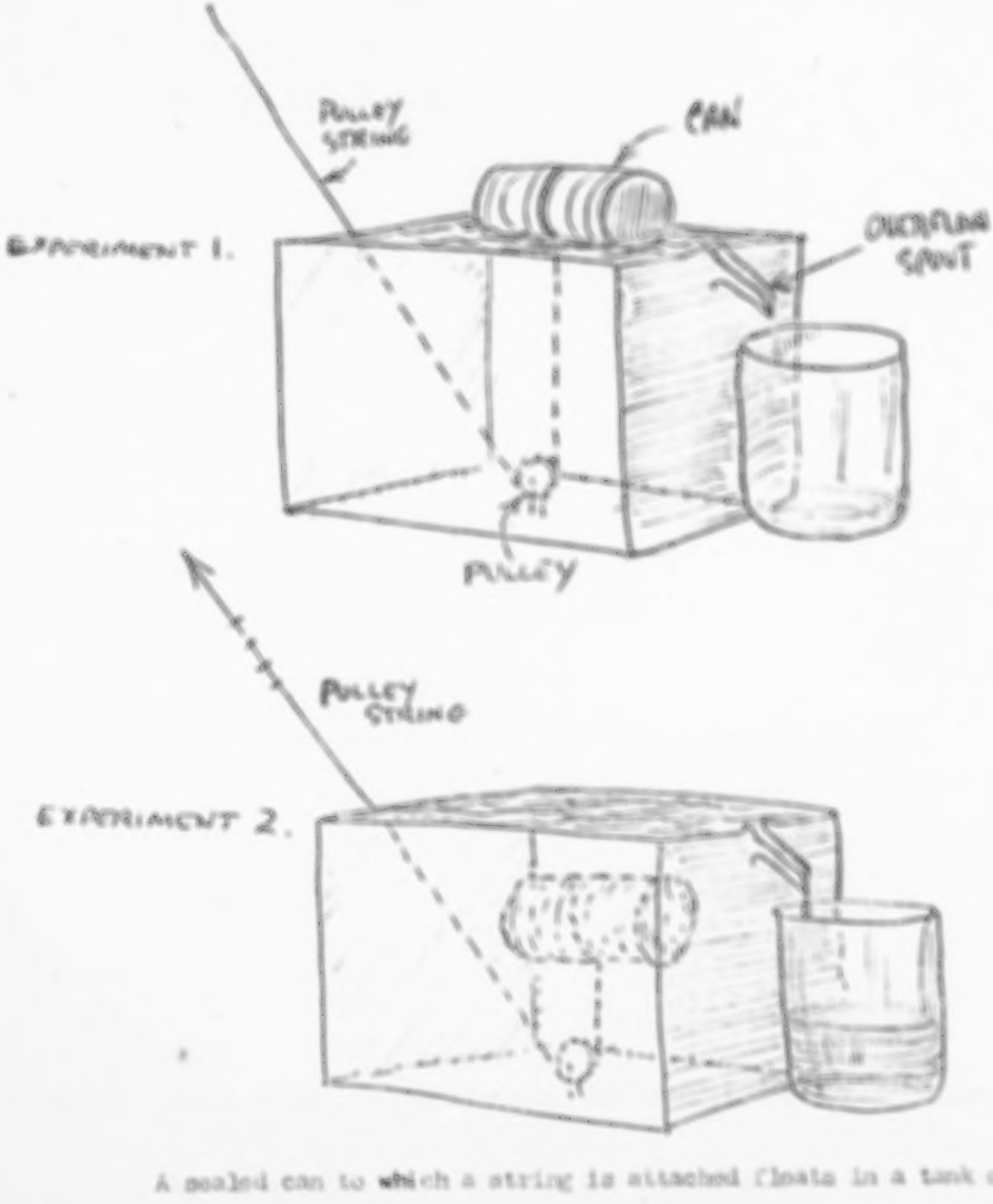
Part B. Under which of the following conditions will water change to a vapor?

1. When water is hot.
2. When water is cool.
3. When water is boiling.
4. All of the above.

Part C. Which rule best explains the correct answers to Parts A and B?

1. Air does not contain water.
2. Water can exist as a gas or as a liquid and can change form.
3. Cool water does not vaporize.
4. Water vaporizes only when boiling.

PROBLEM IX


PULLEY STRING
CAN
EXPERIMENT 1.
OVERFLOW SPOUT
PULLEY
PULLEY STRING
EXPERIMENT 2.

A sealed can to which a string is attached floats in a tank of water which has been filled up to the overflow spout.

The can is then pulled under water (by the use of the string and a pulley) and held there.

Some of the water will overflow from the tank.

Problem IX

Part A. The weight of the water which overflowed is:

1. More than the weight of the can.
2. Less than the weight of the can.
3. The same as the weight of the can.

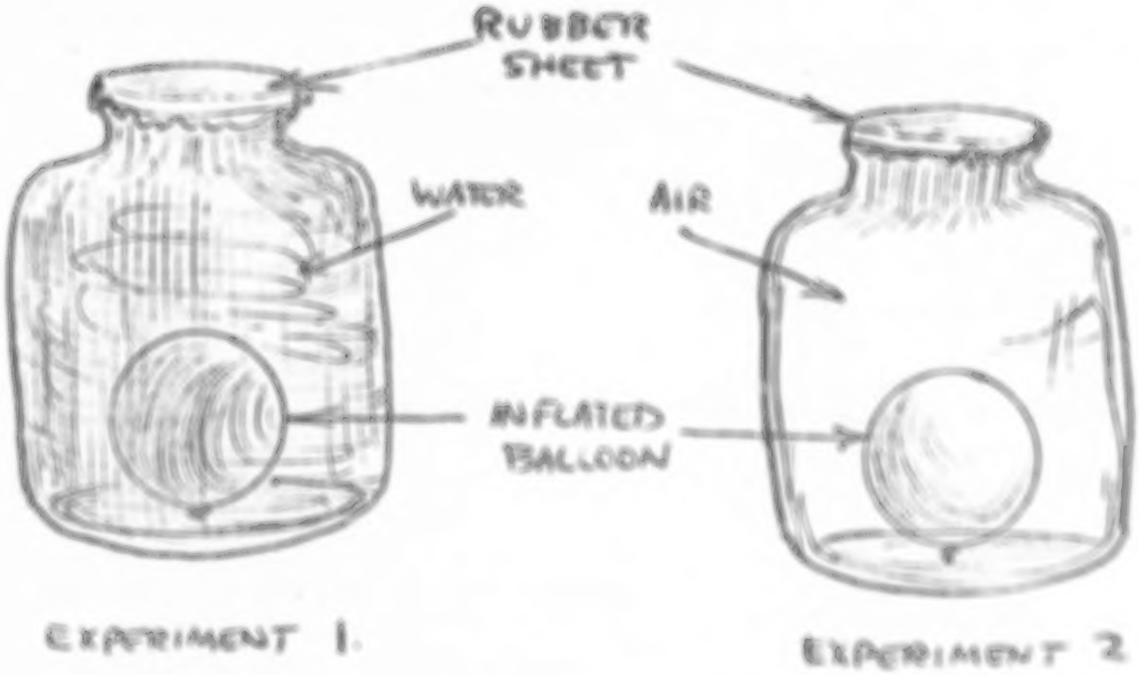
Part B. What could you do to the can in Experiment 1 to make it sink?

1. Make its size greater.
2. Make its weight greater.
3. Make its weight less.
4. Stop up the overflow spout so the water cannot escape.

Part C. Which of the following rules best explains the correct answers to Parts A and B?

1. An object will float if it weighs less than the amount of water it displaces.
2. An object will float if it weighs more than the amount of water which it displaces.
3. An object will float only if it is made of material that is lighter than water.
4. Objects float when they have air spaces in them and sink when they do not have air spaces in them.

PROBLEM X


RUBBER SHEET
WATER
AIR
INFLATED BALLOON
EXPERIMENT 1.
EXPERIMENT 2

The bottle in Experiment 1 is completely filled with water and the bottle in Experiment 2 contains air.

Balloons are blown up until they are the same size and are tied to the bottom of each bottle. A sheet of rubber is stretched across the top of each bottle so that it is air tight.

Problem X

Part A. If you pushed down equally hard on the rubber coverings of both bottles:

1. The balloon in Experiment 1 would get smaller than the balloon in Experiment 2.
2. The balloon in Experiment 2 would get smaller than the balloon in Experiment 1.
3. Neither balloon would change size.
4. Both balloons would get larger.

Part B. Which of the following is necessary for the balloon in Experiment 1 to get smaller?

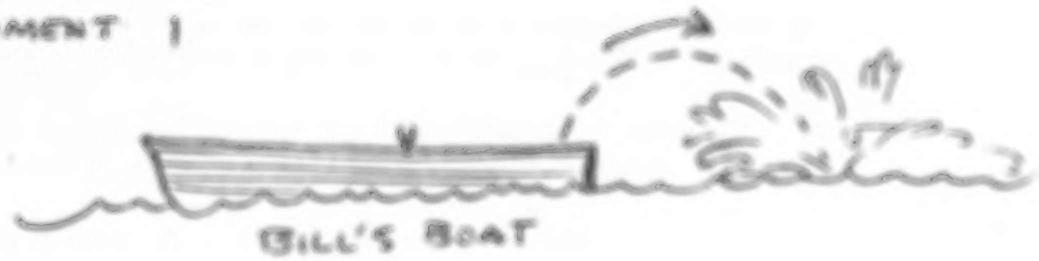
1. The liquid must be water.
2. The balloon must be at the bottom.
3. The balloon must contain a gas.
4. The pressure of the air in the balloon must be the same as that of the air outside the bottle.

Part C. Which of the following properties of water makes this demonstration possible?

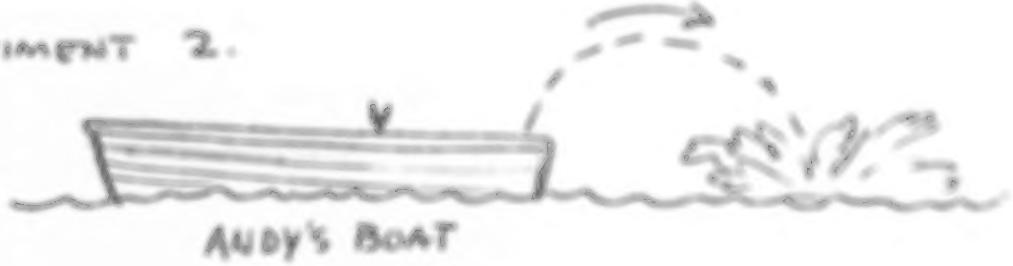
1. Water is more compressible than air.
2. Water is less compressible than air.
3. Water is heavier than air.
4. Water flows.

PROBLEM XI

EXPERIMENT 1



EXPERIMENT 2.



Two boys are sitting in identical boats. Andy weighs 15 pounds and Bill weighs 75 pounds. They both dive the same distance into the water and with the same speed.

Problem XI

Part A. What will happen to the boats?

1. Both boats will move the same distance in the direction opposite from the direction of the dives.
2. The boats will not actually move but just rock.
3. Both boats move in the direction opposite from the direction of the dives but Bill's boat will move a greater distance.
4. Both boats will move in the direction opposite from the direction of the dives but Andy's boat will move a greater distance.
5. Both boats will move the same distance but in the same direction as the dives.

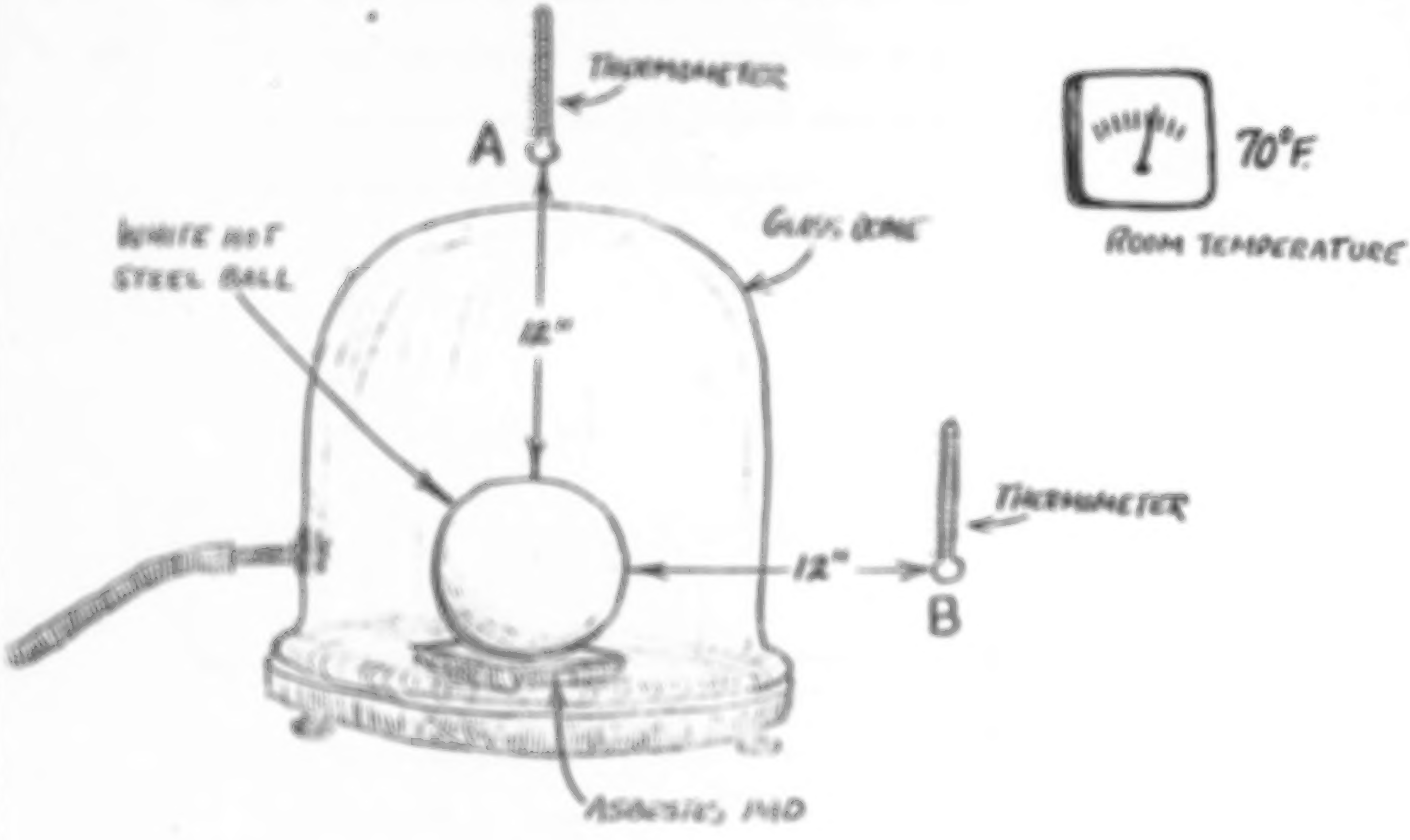
Part B. What conditions would make both boats move the same distance?

1. Same conditions as described in Part A.
2. Have two boys the same weight.
3. Have Bill dive faster than Andy.
4. Have Bill dive farther than Andy.

Part C. Which of the following best explains the correct answers to Parts A and B?

1. For every action there is an equal and opposite reaction.
2. The faster you move the farther you go.
3. Heavy objects have more force when they move.
4. Light objects move faster and have more force than heavy objects.

PROBLEM XII


THERMOMETER
A
70°F.
ROOM TEMPERATURE
WHITE HOT STEEL BALL
GLASS DOME
12"
THERMOMETER
12"
B
ASBESTOS PAD

A white hot steel ball is covered with a glass dome and then all of the air is pumped out of the dome through the tube.

A thermometer is held at point A and another at point B so that both thermometers are exactly 12 inches from the ball.

The room temperature is 70°.

Problem XII

Part A. What results would you notice an hour later?

1. The temperature at A is higher than at B.
2. The temperature at B is higher than at A.
3. A and B are the same temperature.

Part B. Which of the following is necessary in order for heat to transfer from the ball to the thermometer?

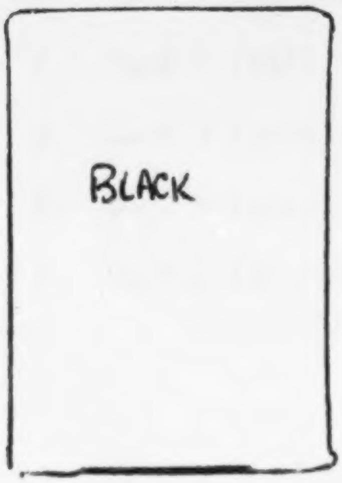
1. The ball and the thermometer must be connected by a metal conductor.
2. Air must be present for convection.
3. The thermometer must be directly above the source of heat.
4. There must not be a substance between the ball and the thermometer which absorbs all the radiant heat.

Part C. Which rule best explains the correct answer to Parts A and B?

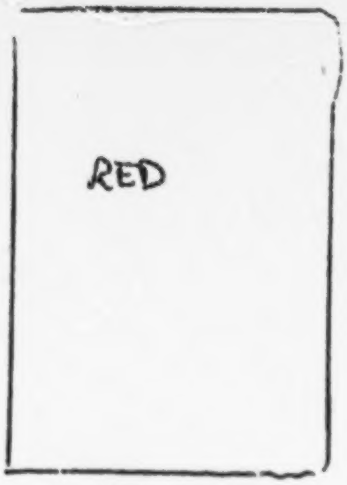
1. Heat is conducted from molecule to molecule.
2. Heat is transferred from molecule to molecule in air.
3. Heat always rises.
4. Heat may be transferred by radiation even through glass.
5. Heat cannot go through glass or any solid object without touching the object.

7

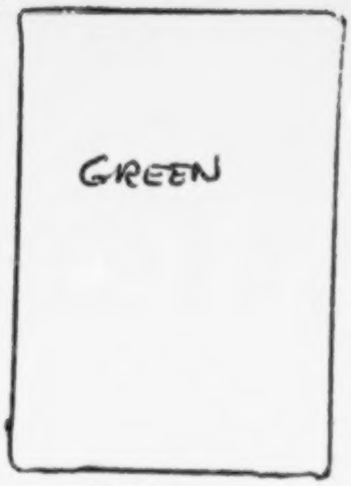
PROBLEM XIII



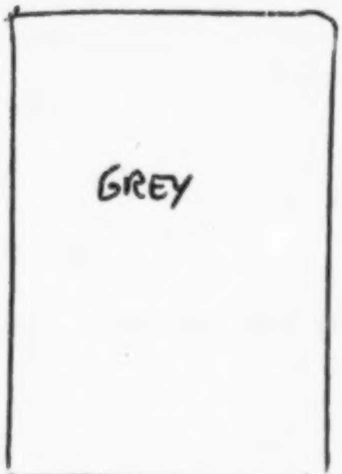
CARD 1.



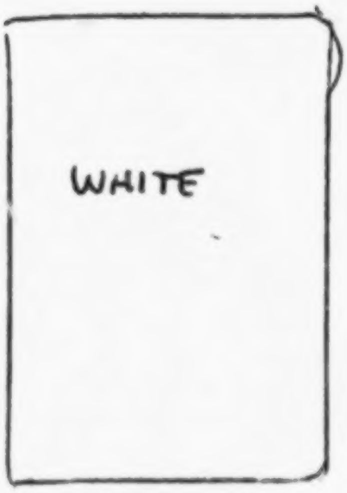
CARD 2.



CARD 3.



CARD 4.



CARD 5.

Five cards of the same material, shape, and size, but of different colors (as shown in the pictures) are placed in the sunlight for several hours.

The temperature of each card is then measured.

Problem XIII

Part A. Which card will be the hottest?

1. Card 1 (black).
2. Card 2 (red).
3. Card 3 (green).
4. Card 4 (grey).
5. Card 5 (white).

Part B. Which kind of colors absorbs the most heat?

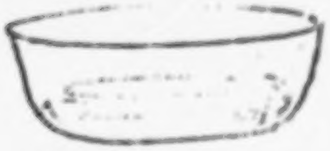
1. Bright colors.
2. Light colors.
3. Dark colors.
4. Neutral colors.
5. "Warm" colors like red and yellow.

Part C. Which rule best explains the correct answer to Part A?

1. Black absorbs heat better than any other color.
2. Rainbow colors absorb heat better than black, white, or grey.
3. The colors of a flame (red and yellow) get hotter than the colors of water (blue and green).
4. Grey gets the hottest because it has all the colors of the rainbow in it.

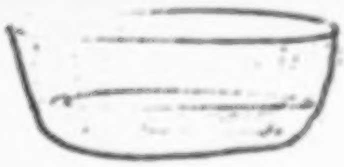
PROBLEM XIV

WATER AT 33°F.



EXPERIMENT 1.

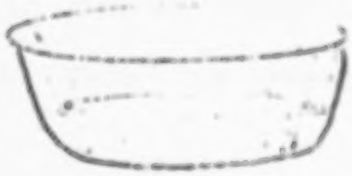
WATER AT 98.6°F.



EXPERIMENT 2.

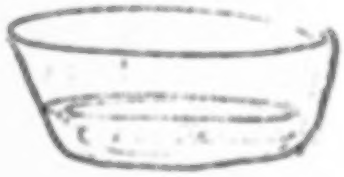
70°F
ROOM
TEMPERATURE

WATER AT 137°F.



EXPERIMENT 3.

WATER AT 200°F.



EXPERMENT 4.

The four pans of water shown in the pictures are identical except for temperature. The pans are located in different rooms. Each room contains dry air. The air in the rooms has a temperature of 70°.

After some time, a noticeable amount of water will evaporate from each pan.

Problem XIV

Part A. From which pan will the greatest amount of water evaporate?

1. The pan in Experiment 1.
2. The pan in Experiment 2.
3. The pan in Experiment 3.
4. The pan in Experiment 4.
5. The same amount will evaporate from each pan.

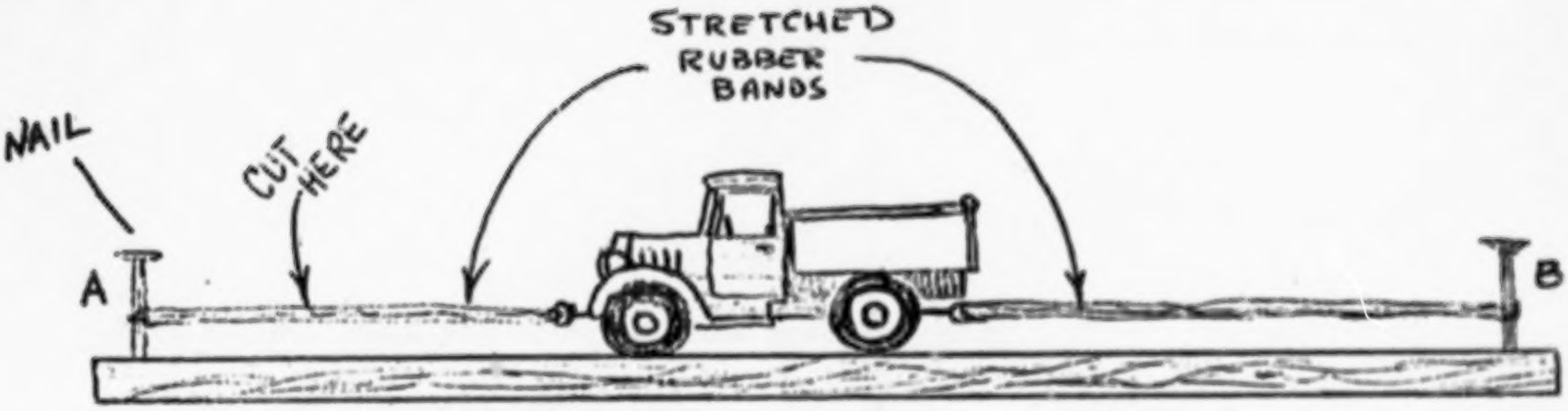
Part B. What could you do to make a liquid change to a gas more rapidly?

1. Pour more liquid into the pan.
2. Make the surface area of the liquid less.
3. Put the liquid in a deeper pan.
4. Raise the temperature of the liquid.

Part C. Which rule best explains your choice for Part A?

1. The rate of evaporation depends in part on the temperature of the liquid.
2. The rate of evaporation is greater in warm liquids than in cold liquids.
3. The rate of evaporation is greater in cold liquids than in warm liquids.
4. The rate of evaporation does not depend on the temperature of the liquid.

PROBLEM XV


STRETCHED
RUBBER
BANDS
NAIL
CUT HERE
A
B

A toy truck is held by rubber bands in the position shown.

Problem XV

Part A. If the rubber band is cut at the place marked by the arrow, the truck woul:

1. Move toward A.
2. Move toward B.
3. Not move.
4. Fly straight up.

Part B. How could you make the truck move toward A?

1. Cut the other rubber band.
2. Change the rubber bands before starting the experiment.
3. Drive the nail at A further in.
4. Take the wheels off the car.

Part C. Which rule explains why the truck moved?

1. Whenever a force acts on an object, that object must move.
2. Whenever two forces act on an object, that object does not move.
3. When an object is moving, the forces acting on it are in balance.
4. When an object is set in motion, the forces acting on it are not in balance.